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Journal

—OF THE—

American Ceramic Society

A Monthly Journal devoted to the Arts and Sciences Related to the Silicate Industries.

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JOURNAL
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EDITORIALS.

THE PATENT OFFICE AND THE PATENT SITUATION.

By George E. Middleton, an Assistant Examiner, U. S. Patent Office.

In view of the editorial on "The Patent Situation" in the September number of the Journal of the American Ceramic Society,[1] in which our patent system, and particularly the Patent Office, was so bitterly arraigned, it has seemed advisable to submit the following, partly by way of defense of those charged with the administration of the Patent Office, but more particularly by way of a general survey of the field, pointing out some of the reasons why the office has, in a measure, failed to fulfill its high duty, and some of the reforms now in contemplation. This is done with the hope that the American Ceramic Society may, the more effectively, lend its influence in the achievement of these reforms.

The industrial development of America under the present patent system administered through the Patent Office, has certainly justified the judgment of its founders. But the industrial arts have progressed faster than the system designed to promote that progress. Such a situation cannot long endure and it is becoming increasingly evident to those conversant with the facts that reform is urgent if the system is to continue to justify its existence. The problem is a big one, but not impossible of solution.

Historical.

The framers of the Constitution appreciated the wisdom of encouraging invention by the grant of some suitable reward to

[1] *J. Am. Ceram. Soc.*, **1**, 59 (1918).

inventors. It was first proposed that: "The Congress shall have power to encourage by premiums and provisions the advancement of useful knowledge and discoveries"—but this was abandoned in favor of a monopolistic grant, the provision adopted being—"The Congress shall have power * * * * to promote the progress of science and the useful arts by securing for limited times to * * * inventors the exclusive right to their * * * discoveries." (Art. I, Sec. 8.) There are two systems under which this monopoly may be secured. Under one, the applicant is granted his patent as a matter of course, the Patent Office acting merely as a recording or registration bureau, the question of validity being left entirely with the courts. This is known as a registration system. The other requires an examination into the merits of the alleged invention by a corps of experts and the grant of the patent carries with it *prima facie* presumption of validity. This is known as an examination system. Under a registration system, the burden of proving validity is upon the patentee and his is the responsibility for claiming no more than he is justly entitled to. If he claims too much, his whole patent may be declared invalid even though some of his claims may be limited to his real invention. Under an examination system, the burden of proving invalidity is upon the infringer and as the Patent Office itself has essayed to pass upon the claims, patents are never declared wholly void because some of the claims may be too broad.

Both systems have been tried in this country. Acting under its constitutional authority, Congress passed the first patent act in 1790. The system thus established was an examination system and so rigorous was the examination and so high the standards set for those entitled to the grant, that during the three years of its existence only 60 patents were issued. The industries complained loudly against this severity and in 1793 the original act was superseded by another. The pendulum had swung to the other extreme for the system under the act of 1793 was wholly a registration system. This obtained until 1836, but proved grossly unfitted to the needs of the country and was fruitful only of abundant ligitation, fraud and confusion. By 1835, conditions had grown so intolerable that John Ruggles, a senator from

Maine, moved that the Senate appoint a committee to investigate the patent situation. This was done and Ruggles was made Chairman of the Committee which made its report in April, 1836, and at the same time submitted a plan for the reorganization of the Patent Office. The indictment of the registration system returned by Ruggles in this report contains some significant charges—significant because substantially the same as those heard today directed against our present system. He said in part:

"The extent of the evils resulting from the unrestrained and promiscuous grants of patent privileges may be imagined when it is considered that they are now issued, since this year commenced, at the rate of more than a thousand a year; a considerable portion of which are doubtless void for want of originality in the inventions patented, either in whole or in some of the parts claimed as new.

"A necessary consequence is that patents, even for new and meritorious inventions, are so much depreciated in general estimation that they are of but little value to the patentee, and the object of the patent laws, that of promoting the arts by encouragement, is in a great measure defeated.

"To prevent these evils in future is the first and most desirable object of a revision and alteration of the existing laws on this subject. The most obvious, if not the only means of effecting it, appears to be to establish a check upon granting of patents, allowing them to issue only for such inventions as are in fact new and entitled by the merit of originality and utility to be protected by law. * * * * *"

This arraignment evidently had its effect, for before the end of the year, Ruggle's plan had been placed upon the statute books and remains today, except for minor changes, our fundamental law of patents and the foundation of our present examination system.

Thus we see that the registration system was tried in this country for more than forty years, that it was found wanting and was superseded by an examination system under which patents do not issue as a matter of course, but only after an examination which convinces those in authority that the applicant has truly invented something new and useful. That an effective examination system is superior to one based on registration is pretty generally conceded and it is noteworthy in this connection that among the great industrial nations of the earth today, only one—France—still adheres to the old registration scheme.

The Functions of the Patent Office under Our Examination System.

The functions of a patent office under a registration system are relatively simple as the duty of passing upon the merits of an invention is thrown upon the courts. It is obvious that under an examination system, a patent office must be a much more complex institution. The Revised Statutes provide that:

"Any person who has invented or discovered any new and useful art, machine, manufacture, or composition of matter, or any new and useful improvements thereof, not known or used by others in this country, before his invention or discovery thereof, and not patented or described in any printed publication in this or any foreign country, before his invention or discovery thereof, or more than two years prior to his application, and not in public use or on sale in this country for more than two years prior to his application, unless the same is proved to have been abandoned, may, upon payment of the fees required by law, and other due proceeding had, obtain a patent therefor (Sec. 4886).

"Before any inventor or discoverer shall receive a patent for his invention or discovery, he shall make application therefor, in writing, to the Commissioner of Patents, and shall file in the Patent Office a written description of the same, and of the manner and process of making, constructing, compounding, and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art or science to which it appertains, or with which it is most nearly connected, to make, construct, compound, and use the same; * * * * and he shall particularly point out and distinctly claim the part, improvement, or combination which he claims as his invention or discovery." (Sec. 4888.)

There are then, so far as the merits of the case go, four essential prerequisites to the grant of a patent. The applicant must have:

1. *Invented* something.
2. It must be *new*.
3. It must be *useful*.
4. It must be *fully and clearly* disclosed in the application and *distinctly claimed*.

It is further provided:

"On the filing of any such application and the payment of the fees required by law, the Commissioner of Patents shall cause an *examination* to be made of the alleged new invention or discovery; and if on such examination it shall appear that the claimant is justly entitled to a patent under the law, and that the same is sufficiently useful and important, the Commissioner shall issue a patent therefor." (Sec. 4893.)

This examination must, therefore, concern itself in the main with the four essential prerequisites enumerated above, and it is the simple function of the Patent Office to conduct such examination and to grant or refuse to grant patents in the light of its results. But an honest study of an application from these four points of view is neither a simple nor an easy matter.

Invention.—Granting novelty and utility and all the rest, has the applicant exercised that indefinable something known as the inventive faculty? If he has done no more than the skilled mechanic might well have done under the circumstances, if he is a mere technical Philistine, then the grant should be withheld. The patent laws wisely extend protection only to *inventors*. The determination of this question requires a clear judgment, together with an understanding of the development of the particular art. Of course standards vary, not only from time to time, but among individual examiners. From 1790 to 1793 the standard was probably too high; today it is probably too low and must continue so as long as the constant pressure of incoming applications makes it imperative that they be got rid of with greater dispatch than is consistent with careful thought.

Novelty.—This is a purely objective test. In the last analysis, determination of invention is a matter of opinion, but not so novelty. The claim to novelty admits of concrete disproof and it is the duty of the examiner to search for the evidence. If the alleged invention was described in a printed publication anywhere, in any tongue, at any time prior to the filing date of the application, the examiner, if functioning properly, should find it and reject the claims upon it. If the alleged invention was publicly known or used, or on sale by others in this country before the filing date of the application, even though never described in a printed publication, the examiner, if he be a thoroughly efficient examiner, should know of it and reject the claims accordingly. Certainly the main work of the Patent Office today is the determination of this question of novelty. It is this which involves "the search." No expert, however wise short of omniscience, can determine novelty without a search of the prior art, and the value of his determination will be in direct proportion to the thoroughness of that search.

Utility.—Greater than invention, greater than novelty, utility is hardly considered by the Patent Office. The Statutes direct the Commissioner to issue a patent when, upon examination, it shall appear that the alleged invention is *sufficiently useful and important.* And why not? The whole patent scheme was created to promote the progress of the *useful* arts. But how can the academic Patent Office pass upon utility? The truth is that it cannot and does not. Where the alleged invention is frivolous, or obviously inoperative or injurious to public health or morals, a patent is refused, but in other cases, the test of utility is left for the tribunal of experience. On this issue, the applicant, like the pleader at common law, is willing to put himself upon the country. Rejections on the ground of inoperativeness are not infrequent, but the judgment of the examiner is based on purely *a priori* considerations where all the conditions set forth by the applicant are not old. For years, claims drawn to heavier-than-air flying machines were complacently rejected on the ground that such machines were impossible! The office, absolutely without means of making the simplest tests for itself and realizing the occasional folly of academic reasoning, has, on the whole, however, fallen into the unfortunate habit of resolving doubts on the score of inoperativeness in favor of the applicant. The present method of considering utility is not much different from that employed under a registration system.

Disclosure and Claims.—A patent is a contract, the inventor and the public being the high contracting parties. The inventor discloses his new and useful invention to the public, teaching it its principles and its application; the public, in consideration for this disclosure, grants to the patentee for the term of seventeen years, the exclusive right to make, use and vend the subject-matter of the invention. If the subject-matter of the patent is neither indicative of invention, nor new, nor useful, it is clear that the patentee has failed to give consideration for his monopoly and that the contract is void. But this fourth element of the patentee's consideration, disclosure, is of equal importance. If the public is not clearly and accurately taught how to avail itself of the invention, of what value is it? It is, therefore, the duty of the examiner to see that no essential information is omitted,

that each patent is so full and complete in itself that anyone skilled in the art to which it pertains can readily apply the invention, guided by the specification. Where doubt arises as to the completeness of disclosure, tests should be made, but these the Patent Office is without facilities to make.

In describing his invention, an inventor must, of necessity, give it a setting in the prior art. Therefore, the relation of the invention to the prior art must be set forth. But this description is not sufficient to define the invention and, from the specification alone, it would be impossible for the public to know exactly the scope of the monopoly which is granted. For this reason the description or specification must conclude with a specific claim or claims defining the metes and bounds of the invention. It is the duty of the examiner to see that these claims embrace neither more nor less than the applicant is entitled to. Under a registration system, this is not so, the applicant himself assuming the burden of claiming no more than his invention.

A true examination system then differs from one based solely on registration mainly in the method of passing upon invention, novelty and utility, and where, from one cause or another, consideration of invention becomes perfunctory, determination of novelty superficial, and judgment upon utility left for the High Court of Experience, the system is substantially a registration system. This is the crux of the whole matter.

Some Reasons Why the Patent Office Has Failed to Function Successfully.

The failure of the office to cope successfully with the problem is not strange. The industrial development of the world within the past fifty years is among the striking phenomena of history and in this development America has taken the lead. The Patent Office is the pulse of this quickened industrial life. To date, 1,300,000 patents have been granted and by the close of the decade another 100,000 will easily have been added. The million mark was passed only in 1911. This means that in this present decade 400,000 of the 1,400,000 patents will have been granted, or 28 per cent of the patents in 12 per cent of the time, and the end is not yet. It required 75 years to complete the first million,

the second will undoubtedly be rounded out in 20, and so on, *ad infinitum*.

The number of patents granted by foreign countries has also increased similarly until today the total approximates 2,700,000. At the same time, the mass of scientific and technical publications has grown to a prodigious size and is constantly increasing with accelerating speed. And then besides these printed evidences of scientific and industrial growth, there is another and perhaps a vaster fund of knowledge and experience resident in unwritten and unpublished shop and laboratory practice—things so well known to the workers that no one has deemed it worth while to mention them in print, and yet these are the very fundamental things that keep the wheels of earth turning. Indeed, the sum total of human knowledge in this one field of industrial arts is something stupendous—certainly enough to discourage the most erudite examiner of patents.

The examining force of the office has been slightly increased to keep pace with this mighty advance, but the increase has been ridiculously inadequate. In 1890, the corps comprised 159 assistant examiners (the ones who make the searches) and in 1917, 360. In 1890, the number of applications received was 41,048, and in 1917, 70,373. This means 258 new applications examined per man in 1890 and only 195 in 1917, *but*, the field of search in 1890 was much smaller than in 1917. In the former year, the number of United States patents then granted was 443,000 and the available foreign patents 635,000, making a total of 1,078,000. At the close of 1917, there were 1,251,000 United States and 1,770,000 available foreign patents, making the available field of search in patents alone 3,021,000. The work done by an examiner in novelty searches varies directly as the product of the number of applications received multiplied by the field of search, and inversely as the number of assistant examiners. The work done by an examiner in his consideration of an application aside from the search varies directly as the number of applications and inversely as the number of assistant examiners. An examiner's time is about equally divided between searching and these other duties. These two ratios may be designated as the index of work of their respective kinds. In any given year, if A = applications

received, S = the field of search, E = the assistant examiners, W' = the index of search work, and W'' = the index of work other than searching, then

$$W' = \frac{A \times S}{E} \qquad W'' = \frac{A}{E}.$$

Expressed in tabular form, reducing the indices of work for 1890 to 100 and taking the mean of these as W, the true index of work, the above figures reduce to

	A.	S.	E.	W'.	W''.	W.
1890	41,048	1,078,000	159	100	100	100
1917	70,373	3,021,000	360	279	72	175

In other words, as the time spent in examinations does not vary materially, the quality of the work done in 1917 was about four-sevenths of that in 1890. In order to have maintained the quality of 1890, it is obvious that the number of assistant examiners in 1917 should have been 75 per cent greater than it was, or 630.

It is to be observed that these figures utterly fail to take into account either the scientific and technical literature or the known shop practice, both of which, as above pointed out, have increased enormously since 1890. The consideration of these elements would vastly increase the field of search factor for 1917 as compared with that of 1890 and so correspondingly increase the index of work for 1917. It is also to be borne in mind that the taking of the figures for 1890 as a basis for comparison is by no means an assumption that conditions at that time were ideal. They were undoubtedly far from it. The comparison merely shows that conditions are growing worse.

The total average time given by an examiner to each application based on the 1917 figures is about nine and one-half hours. Not more than half of that time is given to actual searching; the other half is consumed in reading the case, noting informalities, writing the necessary letters, studying new claims presented by amendment, etc. And as this nine and one-half hours represents the quotient of the examiner's *entire* time divided by number of applications, any stray moments devoted to an attempt to keep in touch with the development of his art must be deducted from

it. Validity searches require weeks. Is it any wonder that validity searchers sometimes discover references overlooked by or unknown to the examiner? As a conservative estimate based on the foregoing data, the present examining corps should be doubled.

The Patent Committee of the National Research Council in their report to be mentioned later, state:

> "The patents granted by the United States Patent Office are of less average probable validity than formerly because the number of applications for patents and the field of search are constantly increasing, while the examining force for many years has been insufficiently large and has not been increased proportionately. The inducements are so unattractive that 25 per cent of the examining force has resigned within the past three years. * * * *
>
> "The work of the Patent Office has grown so much more rapidly than has the examining force that the examination to determine whether or not the invention claimed in an application for patent is novel is imperatively restricted to the field of search where it is most likely that the invention will be found. *Many patents are granted which would not be granted if the examiner had time to make a thorough search.* * * *"

It is not possible to estimate the probable validity of the patents now granted. In the adjudicated patents reported in the Official Gazette of the Patent Office for 1918, the issue of validity was raised in suits involving 135 patents and of these, 75 were declared valid, and 60, or 44 per cent, invalid, either in whole or as to some of the claims. Of these 60, at least 55 were invalidated for lack of invention in view of the prior art. This percentage of invalid patents for 1918 seems high, but it must be borne in mind that during that year there were 587,000 unexpired patents in existence. Many of these were so limited, unpractical, or out of date, that they would never get into litigation and many so clearly recognized as valid that they also would never appear in court. No one can say what the average probable validity of the patents now granted is, but in view of the necessarily limited search and the tendency to lower standards of invention now prevailing, it must be, as the National Research Council pointed out, less than formerly. The noteworthy thing, however, is not that invalid patents are granted, but that examiners circumscribed and limited in the exercise of their duties as the present examiners certainly are, should be able to issue so many patents of proved validity.

Some Proposed Reforms.

The writer of the editorial in question believes that the situation, bad as it is, admits of easy solution. He proposes a remedy which is "neither difficult nor complex" and which consists in the simple "creation of a small committee of experts for each of the natural divisions of industry and technology, among them one for the field of ceramics." If applications were filed, a score a week, this small committee of experts might develop into a highly efficient and satisfactory examining corps, but how could they cope with a flood of 1500 applications a week? The present examining corps—a committee of 400 experts—finds itself unequal to the task. As previously pointed out, a search of the prior art is necessary before the simplest idea can be patented. No committee of experts can possibly pass upon novelty out of the fullness of their experience alone and is it to be expected that they could search with much greater efficiency and speed than the present corps? It is feared that the proponent of this apparently simple remedy has failed to grasp the magnitude of the task with which the Patent Office finds itself confronted.

In 1917 the Patent Office Society was organized with the object, as set forth in its constitution, "to further the industrial development of the United States in so far as the patent system is a factor thereof, to promote and foster a true appreciation of the American patent system, to cultivate a high standard of professional ethics among patent practitioners and examiners, and to promote the professional, intellectual and social welfare of the members of the Society."

The first fruits of the Society's activities have developed through its affiliation with the National Research Council. This Council in conformity with a request embodied in a resolution adopted by the Patent Office Society and fully concurred in by the Commissioner of Patents, appointed a committee for the study of Patent Office problems. That committee consisted of five scientists and three members of the Patent Bar Association, all men of national prominence in their chosen fields. They were Dr. William Durand, Dr. Leo H. Baekeland, Dr. M. I. Pupin, Dr. R. A. Millikan, Dr. S. W. Stratton, Dr. Reid Hunt, Mr. Frederic

P. Fish, Mr. Thomas Ewing and Mr. Edwin J. Prindle. Mr. Ewing was Commissioner of Patents from 1913 to 1917. The recommendations of this committee may be epitomized as follows:

1. A Single Court of Patent Appeals.
2. The Patent Office a separate institution, independent of the Interior Department.
3. Increase in force and salaries of the Patent Office.
4. Compensation for infringement of patents.

A bill embodying the statutory changes necessary to put these recommendations into effect has been drafted and will be presented to Congress in the near future.

Recommendations 1 and 4, although of great importance, do not directly affect the Patent Office and the granting of patents and so will not be discussed in this paper. Recommendations 2 and 3 do affect the Patent Office.

The establishment of the Patent Office as a separate institution would be the first step toward that larger usefulness which the office believes to be its rightful destiny. It was only a few years ago that the Department of Agriculture was itself a minor section of the Patent Office. Witness its position today—a great government department comprising many specialized bureaus. And yet the Department of Agriculture is charged only with the duty of promoting the progress of one industry. The Patent Office, charged with the duty of promoting the progress of *all* science and *all* the industrial arts, is but a small bureau of the Interior Department. The situation is anomalous.

The need for an increase in the force of the Patent Office is obvious, as formerly pointed out, if only to maintain past standards. If improvement is sought, the need becomes imperative. But an increase in the force alone is not a cure-all. The equipment is insufficient. The office has no laboratory of any kind nor is there any machinery by means of which it can adequately coöperate with other government bureaus possessing this equipment. The library facilities are insufficient. The scientific library of the Patent Office ought to be second to none and yet Congress allows only three thousand dollars a year for the Patent Office to keep up with all the technical literature of all the arts. The examiners are too academic and a mere increase

of the corps will not permanently better this. It should be a duty of the examiners to acquaint themselves with the actual practice in the arts which they are examining by periodic visits to the manufacturing establishments of the country. But such visits are very rare. There is an annual fund of five hundred dollars drawn on for this purpose—about $1.25 (one dollar and a quarter) per examiner! But the addition of 200 assistant examiners, as proposed by the National Research Council, would be a blessed relief. It would enable each examiner to spend fifty per cent more time on each application and so tend to make his work just fifty per cent more thorough and efficient than it can be today.

Reforms cannot be effected in a minute. Although some of us feel that the recommendations of the Patent Committee do not strike deeply enough, they certainly represent a long step forward and with a few minor suggestions, have received the approval of the Patent Office Society. We take this opportunity of commending them to the American Ceramic Society for consideration. If "our whole system of affording patent protection to inventions . . . is without rhyme or reason;" if, "like heaven's mercy, patents fall both upon the just and the unjust and the result is injustice and chaos," the fault does not lie with the Patent Office, but with those who refuse to grant it the equipment and the men without which it can not hope to do its great and useful work.

That the present patent system is defective, no one will deny, but on the other hand, it is not quite so bad as the writer of the editorial in question would have us to believe. He asks whether or not patents have been issued upon the employment of kaolin, feldspar, and quartz in ceramic bodies, and then answers the question in the affirmative. Unfortunately, no patent was cited, but a search in the appropriate class and sub-class has failed to reveal any such patent. It is true that patents have been granted on body mixtures, *containing* those rare ingredients, but there were other things present. Whiteware manufacturers using that ancient trinity of the tri-axial diagram need have no fears of infringement suits. The truth is that errors are often made in construing patent claims by those unfamiliar with such matters, and a claim which may at first glance appear very broad and drawn to

some old and unpatentable composition or device, will often, upon closer scrutiny, prove to be in truth limited to certain details which leave the broad field unrestricted. In criticizing the grant of a patent, the critic should first make sure that he appreciates the exact scope of the matter claimed.

There is another phase of the matter. It takes two to make a patent—the inventor and the Patent Office. If "weird compositions of glasses, enamels and glazes" and kilns and driers "representing ideas hoary with antiquity" are patented, it is to be regretted, but it must not be forgotten that it was a ceramist in the first instance who applied for these patents and took oath that the ideas involved were useful and that he believed them to be new. A cursory inspection of the names of recent patentees in the ceramic arts reveals many of eminence in that field.

THE TWENTY-SECOND ANNUAL MEETING.

The Board of Trustees has voted to hold the Twenty-second annual meeting of the American Ceramic Society at Philadelphia, Pa., February 23–26, with headquarters at the Hotel Walton. The Board is to be commended for arriving at an early decision as to the time and place for holding this meeting. The enlarged membership and the increased scope of the activities of the Society have multiplied the preparations necessary for the annual meeting, and with the early start afforded the Philadelphia convention should surpass, if possible, the banner one held in Pittsburgh last February.

The Society has not held an annual meeting in Philadelphia since 1907. With its excellent railroad facilities and hotel accommodations, it would appear that the selection of Philadelphia as a meeting place is a happy one.

ORIGINAL PAPERS AND DISCUSSIONS.

DEVITRIFICATION OF GLASS.

By N. L. Bowen.

All ordinary glasses are undercooled liquids and as such are unstable. Were the stable condition established all such glasses would be completely crystalline at ordinary temperatures. At these temperatures, however, the rate of establishment of the stable condition, that is, the rate at which crystallization proceeds, is absolutely negligible. At higher temperatures, the rate of crystallization (devitrification) may be great enough to become a seriously troublesome factor to the glassmaker. In the literature of glass technology there occur frequent statements that indicate much confusion of ideas concerning the nature of devitrification. Before describing the specific examples of this phenomenon that have been encountered in the course of the writer's experience in the manufacture of optical glass, it seems desirable to discuss the fundamental principles underlying crystallization or devitrification.

Definite chemical compounds almost invariably have definite melting points and the solid, crystalline substance when raised to the melting temperature usually passes promptly into the liquid condition. If the liquid is then allowed to cool and the conditions are such that equilibrium is attained, crystallization will take place at the temperature of the melting point. Melting is therefore a reversible phenomenon and the melting point of a substance is defined as the temperature at which the crystalline and liquid phases are in equilibrium. It is well known, however, that in many chemical and physical changes equilibrium is not always readily established, and in the case of cooling a molten

substance it is frequently possible to lower the temperature below the melting point without the incidence of crystallization, when the liquid is said to be undercooled.

The ease with which undercooling of the liquid can be accomplished varies enormously from one substance to another. Molten metals, for example, usually crystallize promptly when cooled to the melting point. As a rule, water behaves similarly, but with certain precautions, such as the exclusion of dust particles, bubbles, etc., water can be undercooled. Then, again, there are a great number of substances for which no particular precautions are necessary and which normally undercool. Usually, however, only a certain amount of undercooling can be accomplished and when this has been attained crystallization occurs. There are, however, certain substances that can be undercooled an indefinite amount. Such substances may be considered to pass gradually and continuously from the state of fluent liquid, through a condition of continuously increasing viscosity until finally a rigidity comparable with that of ordinary crystalline substances is attained, though the substance is still, from the point of view of the physical chemist, an undercooled liquid. The substance is then said to be in a vitreous condition or is called, simply, a glass.

Silicates are the best known representatives of this class of substances that can be readily undercooled to a vitreous condition, though there are many more or less related substances that behave similarly, such as borates, and still others wholly unrelated, such as ordinary ethyl alcohol. Indeed, the difference between various substances in this respect is only a matter of degree, and it is probable that all substances could be obtained in a vitreous state if the requisite conditions of cooling could be attained.

The conditions that favor permanent undercooling will be apparent from the following considerations. Above the melting point the tendency of a substance to crystallize is zero; at the melting point it is still zero, but as the liquid is cooled below this point the tendency increases rapidly and if there were no counter effect it would probably increase indefinitely as undercooling is increased. However, as the liquid cools there is a constant diminu-

tion in the freedom with which the atoms can arrange themselves in that configuration characterizing the crystals, because the viscosity or internal friction of the liquid continually increases. The increasing viscosity therefore works against the crystallization tendency and the result is that the actual crystallizing power usually increases rapidly as cooling proceeds below the melting point, passes through a maximum, and falls away practically to zero.

The crystallizing power may be defined as the numbers of centers of crystallization established per unit of volume in unit time. From the considerations outlined above it is apparent that its variation with temperature can be represented by curves of the form shown in Fig. 1. Curve A is that of a substance whose crystallization power increases very rapidly when the melting point is passed and attains a very great value. It represents a substance that is very difficult to cool quickly enough to prevent the formation of numerous centers of crystallization. Curve B is that of a substance in which it is difficult to avoid crystallization, but in this case it is not so much because the absolute value of the crystallizing power is so great at any given amount of undercooling, but because the crystallizing power is comparatively great through a long range of undercooling. Hence it is difficult to cool through this long range at a rate sufficiently great to prevent crystallization. Curve C is that of a substance easily undercooled without crystallizing.

Silicates do not all belong to the class of substances represented by curve C. Compounds such as $MgSiO_3$, Al_2SiO_5, and $CaSiO_3$ belong rather to the class of substances represented by curve B. They, therefore, can be cooled to the vitreous state only when the rate of cooling is made very great. On the other hand, a large number of silicates, particularly those of the alkalis, can be cooled quite slowly without crystallization and therefore might be represented by curve C. Nevertheless they can be crystallized with sufficiently slow cooling.

Since molten silicates have comparatively great heat capacities and are poor conductors of heat, it is not possible to cool a large mass at any very rapid rate. Silicates that crystallize readily, such as $CaSiO_3$, can therefore be cooled to the glassy con-

dition only in a very small mass, usually a few grams. Such silicates cannot, therefore, be used as ordinary commercial glasses, though they may enter into the composition of such glasses because in mixtures their specific properties are modified.

Before passing to the consideration of mixtures, however, it is desirable to consider the heating of an undercooled liquid or

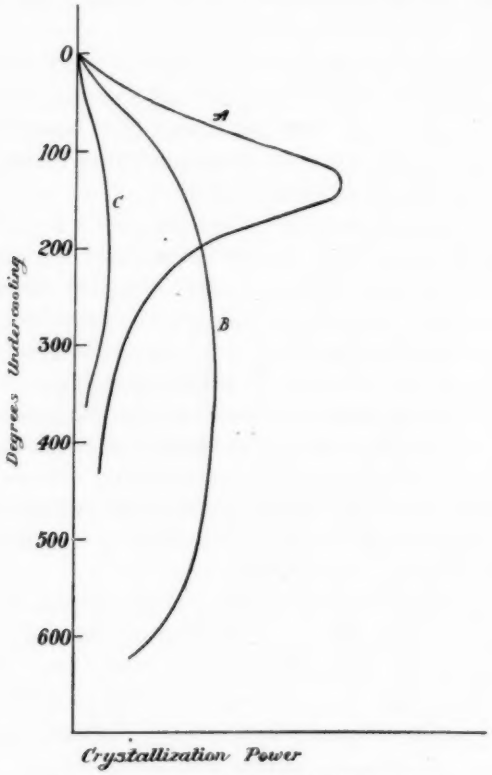

FIG. 1.—Types of crystallization curves.

glass, that is, the reversal of the process of cooling that has been discussed in the foregoing. When such a substance is heated the behavior is the exact reversal of that involved in undercooling. The rigid glass gradually softens, becomes a viscous liquid, and finally a fluent liquid without discontinuity of behavior at

any temperature. Properly speaking, then, a glass has no melting point.

The curves that were given to represent crystallizing power for the liquid which is being undercooled, substantially represent crystallizing power for the reheated glass also. If the substance is of the class of substances represented by curve B, then it must be heated exceedingly rapidly to a temperature above the melting point of the crystalline substance in order to prevent crystallization. Glass of the composition $CaSiO_3$, for example, will crystallize in a short time if held at a temperature even several hundred degrees below the melting point of the crystalline material, and if raised to a temperature not far below the melting point, its crystallization is practically instantaneous. If the behavior of the substance is represented by curve C, on the other hand, then it may be heated slowly and maintained for comparatively long periods at temperatures not far below the melting point of the crystalline substance without crystallization occurring.

In the foregoing, consideration has been given only to the behavior of pure definite compounds. When we pass to mixtures of compounds, as represented in ordinary commercial glasses, we find that certain other factors must be considered. The principles involved in the crystallization of mixtures may be illustrated with the aid of Fig. 2, which represents the crystallization temperatures of all mixtures of $CaSiO_3$ and SiO_2. From the figure it is apparent that, while the crystallization temperature of pure $CaSiO_3$, under equilibrium conditions, is 1540° C, when mixed with 15 per cent SiO_2, its crystallization temperature is lowered to 1490° C, and this is merely the temperature at which crystallization begins. Unlike the pure compound $CaSiO_3$, this mixture does not crystallize entirely at a definite temperature, but as the temperature falls crystallization of $CaSiO_3$ continues and the remaining liquid therefore changes its composition until finally at 1435° C, when the liquid has the composition 78 per cent $CaSiO_3$, the silica begins to crystallize and the whole mass solidifies at this temperature, giving a mixture of $CaSiO_3$ and silica. Such is the behavior when equilibrium prevails, but just as in the case of pure compounds, so in mixtures, undercooling may occur and for similar reasons. Thus the crystallizing ten-

dency of $CaSiO_3$ from the mixture just discussed is zero at all temperatures above 1490° C, while as cooling proceeds below this temperature the tendency increases rapidly, but the counter effect of increasing viscosity enters in so that the actual crystallizing power is never very great. Cooling to a glass is therefore quite readily accomplished with this mixture though so difficult with the pure compound $CaSiO_3$. The effect of the addition of silica is to lower the temperature of crystallization of $CaSiO_3$ to a tem-

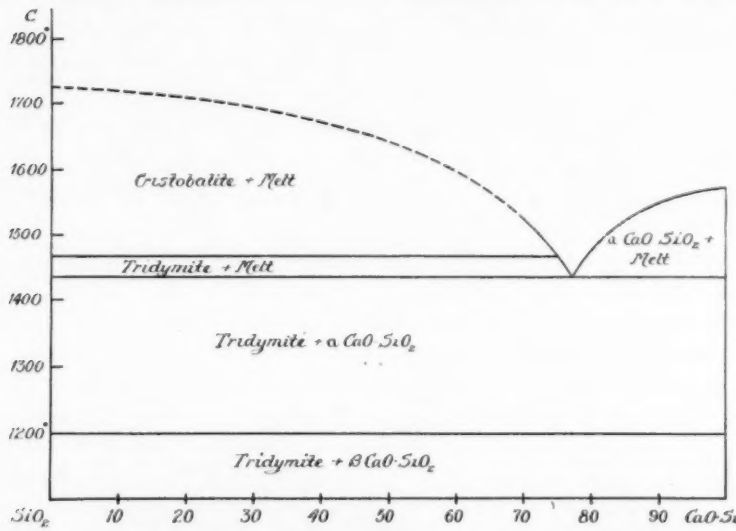

FIG. 2.—Temperature-composition diagram for the system calcium metasilicate–silica ($CaSiO_3$–SiO_2).

perature at which the viscosity is much greater and therefore the crystallization power much decreased. At the same time the silica in virtue of its own inherent properties makes a further addition to the viscosity of the liquid. We thus see that a substance that has a great crystallizing power when pure may nevertheless not separate readily from mixtures, and in general its tendency to separate will be in direct relation to its proportion in the liquid.

In speaking of the cooling of this mixture (85 per cent $CaSiO_3$, 15 per cent SiO_2) it has been stated that below 1490° C the liquid is undercooled. Since we are dealing with a mixture containing

more than one substance we may apply the conception of solutions and the liquid may be said to be supersaturated with respect to $CaSiO_3$ at all temperatures below 1490° C. At 1490° C it is just saturated, and above that temperature it is unsaturated, with respect to $CaSiO_3$. The statement that a certain glass is supersaturated with a certain compound is, therefore, entirely without meaning unless a temperature is specified. Ordinary glasses at room temperature are supersaturated with respect to several compounds, as we shall see in the following.

It has been shown that from the mixture whose crystallization was discussed, crystallization of $CaSiO_3$ began at 1490° C and was continued down to 1435° C when crystallization of silica began, assuming equilibrium. If undercooling occurs, however, the liquid becomes undercooled or supersaturated with respect to $CaSiO_3$ at 1490° C, and undercooled or supersaturated at 1435° C with respect to silica also. Now for each of these compounds there will be a curve of crystallization power, analogous to the curves representing that property that have already been mentioned, though differing, of course, from the curves for the pure compounds in the absolute values represented. In cooling a mixture of the composition discussed, the rate must be made such that the glass does not remain long within the temperature range where the power of crystallization of $CaSiO_3$ or SiO_2, or both, is great. In practice this means that the glass must be cooled rapidly to a temperature at which the crystallization power of these substances is negligible. Similarly, in reheating the glass the temperature should not be raised above that at which their crystallizing power is negligible, or if this is done the time during which it is held above this temperature must be brief, otherwise $CaSiO_3$ or SiO_2, or both, may crystallize out.

When we pass to mixtures of more than two components the same general principles hold, but in this case we have, on cooling, a certain temperature at which the liquid becomes saturated with one of the components, the so-called primary phase, a lower temperature at which it becomes saturated with the secondary phase, and so on, for all the components. If cooling is so conducted, the glass may become undercooled or supersaturated with respect to these various phases at the respective temperatures.

On reheating such a poly-component glass any or all of the components may separate if the necessary relation between crystallizing power and duration of heating is realized.

If we regard the process of manufacture of glass in the light of the foregoing discussion of the theory of devitrification, we find that there are three distinct danger periods during which devitrification is liable to occur. At the full melting or fining temperature no trouble need be anticipated, but when the glass is cooled preparatory to working, some devitrification may occur. Whether the cooling be for the purpose of gathering from pots or from the gathering end of a tank, for the purpose of casting in the case of plate glass or with the object of giving the final stirring before setting out in the case of optical glass, the same considerations apply. The temperature to which the glass is cooled and at which it is usually maintained for long periods must not be such that the glass becomes supersaturated with respect to any of its components; or, stated in another form, the composition of the glass must not be such that it becomes supersaturated with any of the components at the temperature at which it is to be maintained. When devitrification or crystallization does occur at the comparatively high temperature with which we are here concerned, it usually takes the form of the separation of large individual crystals, for the glass is fairly fluid and actual equilibrium conditions may prevail or a sufficiently close approach thereto to allow the crystals to grow slowly by diffusion without the precipitation of the myriad tiny crystals that form when the glass is colder. A particularly good case of this type of devitrification fell under the writer's experience and will be described rather fully here on account of the principles it illustrates and because it affords an example of the application of scientific methods to glass problems.

In the manufacture of the variety of optical glass known as light barium crown much trouble was experienced from the formation of crystals that ruined the greater part of the pot of glass. These crystals formed during the final stages of stirring, immediately preceding the time at which the pot was set out for rapid cooling. The most obvious remedy and the one first tried was to set the pot out at a temperature above that at which the crystals form, and permit the glass to cool more rapidly through

the dangerous temperature. This procedure was entirely successful in eliminating crystallization, but was found undesirable for another reason, *viz.*, that the final stirring of the glass should be conducted at a certain fluidity, and if the pot were set out at a higher temperature then the fluidity of the glass during the final stirring was too great. It was then necessary to attack the problem in another way, and from the principles that have been discussed in an earlier part of the paper it is obvious that if the temperature of final stirring could not be raised then the composition of the glass must be changed so that separation of the crystals would not occur at the temperature normally used. The composition could, of course, have been varied by the method of cut and try, but in this instance the method was adopted of determining the nature of the crystals and deducing therefrom what the change of composition should be. The crystals were very thin hexagonoid plates that probably could not have been identified by purely chemical means, but by determination of optical properties they were identified with the compound $BaSi_2O_5$.[1] Evidently, then, the glass, at the temperature concerned, was supersaturated with $BaSi_2O_5$ and crystallization of that compound could be avoided by lessening the barium content of the glass. At the same time it was desirable to make as little change as possible in the optical properties of the glass so the following method was adopted of determining the minimum amount of decrease in the barium content that would produce the desired effect: The melting point of pure $BaSi_2O_5$ was determined and found to be 1426° C, and the temperature at which the light barium crown glass became just saturated with $BaSi_2O_5$ was determined and found to be 1100° C. The composition of the glass was such that it contained 57 per cent $BaSi_2O_5$, that is, a change of 43 per cent (100–57) lowers the temperature of saturation 326° C (1426–1100). If, therefore, we regard the variation of the temperature of saturation as linear, each further decrease of 1 per cent should lower the temperature of saturation about 7.5° C. This assumption of a linear relation gives, however, only a minimum estimate, because all curves of this nature for silicates

[1] N. L. Bowen, "Crystals of Barium Disilicate in Optical Glass," *J. Wash. Acad. Sci.*, **8**, 265 (1918).

that have been investigated are concave against the temperature axis (see Fig. 2) so that the curve would have the form shown in Fig. 3 rather than the straight line also shown in that figure. A fairly safe assumption is that the curve would have at

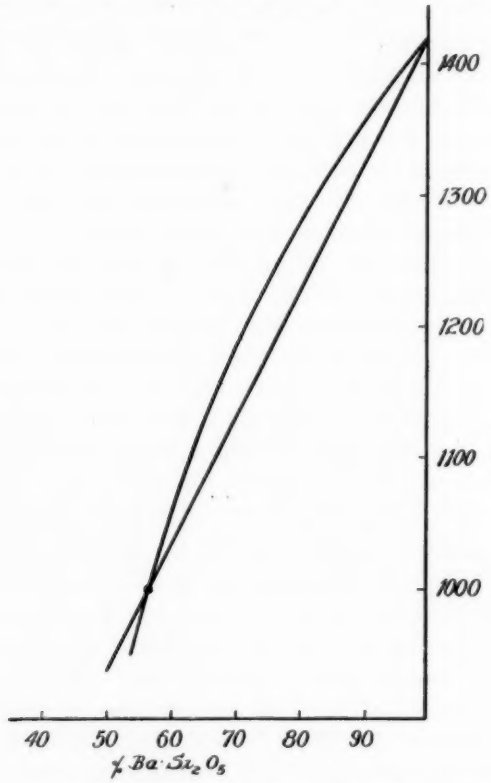

FIG. 3.—Diagram to illustrate the probable form of the curve of saturation temperature of a barium crown glass with respect to barium disilicate.

the point in question about twice the gradient of the straight line and therefore a change of 1 per cent $BaSi_2O_5$ should make a change of about 15° C in the temperature of saturation. Experience had shown that the actual separation of these crystals occurred at a temperature about 70° C above that at which it was desirable to conduct the final stirring. A change of composition

sufficient to reduce the temperature of saturation about 70° C, or a little more, should therefore be ample to permit final stirring at the desired temperature without danger of separation of $BaSi_2O_5$. From the above considerations it is plain that the change of composition should be such as to reduce the $BaSi_2O_5$ content about 5 per cent.[1] Accordingly this change was made and the result was all that could be desired. Thereafter no rejection of light barium crown glass on account of the presence of crystals was necessary.

The case of the separation of $BaSi_2O_5$ is the only example, in the writer's direct experience, of the crystallization of a glass at a comparatively high temperature at which the individual crystals were enabled to grow to comparatively large dimensions. The writer has had submitted to him, however, a sample of plate glass containing crystals of wollastonite ($CaSiO_3$) up to 4 mm. in length that formed in the pot during the "hold-over" immediately preceding the casting of the plate. During casting, the crystals all became arranged with their longer axes parallel to the direction of rolling. The exact conditions under which these crystals formed are not available, but an analysis of the glass, kindly furnished by Mr. F. Gelstharp, shows it to contain a slightly higher amount of lime than normal plate. Whether this slight excess of lime is sufficient to render the glass supersaturated with $CaSiO_3$ at the normal casting temperature is a question. Whether the casting temperature was lower than normal the writer was unable to ascertain, but it seems probable that a combination of these two factors entered into the conditions controlling the separation of the crystals.

Le Chatelier describes some very large crystals of tridymite (SiO_2) that formed in a flint glass that was unintentionally held at a temperature about 800° C for a long period.[2] These crystals evidently grew rather freely under conditions approaching equilibrium and tridymite is the primary phase for glass of that composition. The same glass can be held for moderate periods at

[1] It should be noted that deductions as to changes of composition that will produce a specific result can be regarded as reliable only for small changes close to a known point.

[2] *Bull. Soc. Min. Fr.*, **39** (1916).

800° C without danger of crystallization, so the separation of crystals in the case cited illustrates the importance of the time factor.

Another danger period in the manipulation of glass is that during which it is cooled from its final temperature in the furnace or tank, when it is plastic, to lower temperatures at which it is rigid. During this period it is usually worked into form whether by blowing, drawing, casting, or otherwise, but in the case of optical glass the "metal" is usually cooled in the pot itself. Since the rate at which a large mass of glass can be cooled is limited on account of the low conductivity of glass, the cooling of glass as a large mass in the pot is likely to bring about devitrification. Under these conditions devitrification never takes the form of the separation of large individual crystals but may appear in the form of spherulites (spheroidal aggregates of crystals with a radiating fibrous structure), or in the form of very small crystals evenly disseminated. This latter form of devitrification may give an opalescent glass, a milky glass, or a dense, opaque glass, according to the size of the crystalline particles that separate. In opalescent or milky glass the crystalline particles are beyond the resolving power of the microscope but can readily be detected with the ultramicroscope. In a dense, opaque, devitrified glass the particles can be seen by the microscope and their refraction relative to that of the glass observed. In the writer's experience the crystals are apparently, in nearly all cases, one of the low-refracting forms of silica, namely tridymite or cristobalite. Certain substances, which, for want of a better term, may be called mineralizers, seem to exert an influence in promoting this form of crystallization. Among these are SO_3 and Cl.[1] Arsenic, also, when present in excess of certain amounts, acts similarly, and in one case in the writer's experience the devitrification of a medium flint ($n_D = 1.62$) was eliminated by cutting down the arsenic in the batch from about 0.9 to about 0.3 per cent. Fluorine probably acts in a similar capacity and certain glasses that are deliberately rendered opaque by the addition of fluorides no doubt owe their opacity (crystallization)

[1] Fenner and Ferguson, "The Effect of Certain Impurities in Causing Milkiness in Optical Glass," *J. Am. Ceram. Soc.*, **1**, 468 (1918).

to a separation of crystals that is aided by fluorine. In some cases fluorides themselves may represent the crystalline phase. On the whole, however, little is known of the fundamental facts concerning these opaque and translucent glasses.

More definitely susceptible of solution, however, are the problems connected with the other form of crystallization that takes place during this period of cooling of the glass now being considered. The crystalline constituents of spherulites are readily determinable under the microscope, and, if the heat treatment cannot be varied in such a way as to eliminate their formation, a knowledge of the composition of the crystals enables one to make appropriate changes in the composition of the glass.

The type of barium crown glass whose devitrification at high temperatures has already been described, may further devitrify during the cooling stage with separation of spherulites of $BaSi_2O_5$ that grow about the larger crystals of earlier separation, or with the formation of new simple spherulites. The remedy for this is either (1) the reduction of the $BaSi_2O_5$ content of the glass, just as at the higher temperature (see page 269), or, (2) more rapid cooling. Moreover, even barium crown glass that is safe from devitrification at this stage, in so far as the main mass of glass is concerned, may nevertheless devitrify at the free upper surface of the glass with the formation of spherulites of $BaSi_2O_5$.

From ordinary crown glasses that have an excess of lime as compared with fluxes, spherulites of wollastonite, $CaSiO_3$, sometimes separate during the cooling stage.

Some types of borosilicate glasses may devitrify with separation of spherulites of tridymite, SiO_2. A remedy for this in one instance was found to be the substitution of potash for some of the soda of the glass, a change that probably had the effect of increasing the viscosity and thus diminishing the crystallizing power at the temperature concerned.

The final period of danger of devitrification is one of considerable importance. It is that period during which the glass is reheated, whether for working it into a desired form or for annealing it if it is already in final form. The interrelation of time, temperature, composition and power of crystallization must be carefully borne in mind.

If the glass is to be worked into shape it must, of course, be

heated to a temperature such that it is subject to flow. In the case of optical glass, for example, a common procedure is to heat in molds the rough chunks from the broken-down pot, the operation being conducted at such a temperature that the glass sags down and takes the shape of the mold. There is a certain amount of choice of temperature available, for obviously the sagging will proceed at a certain rate at a certain temperature and at a greater rate at higher temperatures. In the discussion of the principles underlying crystallization it was pointed out that for any glass there is a certain temperature below which the crystallization power is negligible, and another temperature above which the crystallizing power is zero. The lower limit has no special significance in connection with the molding process, for all glasses are too rigid for molding at these temperatures. The upper limit, however, has great importance for if the molding is conducted at a temperature slightly higher than this upper limit there is absolute certainty of freedom from devitrification during the molding itself, though subsequently, of course, proper precautions must be taken to cool at an adequate rate. It is highly desirable, therefore, to know the temperature of this upper limit of devitrification for individual glasses. This temperature is, it will be recalled, that at which the primary phase begins to separate when cooling of the glass is carried on under perfect equilibrium conditions. It is identical with the temperature at which the crystallized glass becomes completely molten as the temperature is raised. This fact can be used in order to determine the temperature of this upper limit. A small piece of devitrified glass is held at a certain temperature for about an hour, is rapidly chilled and examined, this operation being repeated at successively higher temperatures until one is reached at which the last traces of crystals have disappeared. Unless it is undesirable for other reasons, such as the development of bubbles in the glass, molding should be conducted at a temperature slightly higher than that determined by the above method, absolute freedom from devitrification during the molding process itself being thereby guaranteed. Molding can be conducted at lower temperatures with some glasses whose devitrification tendency is small.

The temperatures found for various glasses examined in connection with optical glass investigation are shown in Table 1.

TABLE 1.

Data on Devitrification of Some Optical Glasses.

Glass.	Temperature of disappearance of crystals.		Composition of crystals. (Primary phase.)
Medium Flint (n_D = 1.62).....	910° C.	1670° F.	SiO_2
Ordinary Crown.....	1110° C.	2030° F.	SiO_2
Light Barium Crown.....	1100° C.	2012° F.	$BaSi_2O_5$
Light Flint.....	1115° C.	2039° F.	SiO_2

Glass is frequently reheated not alone for working but also for annealing. All glass must be free from excessive strain that is likely to cause breakage, and optical glass in particular must have the strain reduced below the quite moderate amount that will cause a warping of reflecting or refracting surfaces during grinding and polishing; in short, optical glass must be subjected to fine-annealing. In annealing, the glass is raised to a temperature at which the strain is relieved by relatively slow flow. Obviously there is again a certain amount of choice of temperature permissible, for the flow will take place slowly at low temperatures and more rapidly at higher temperatures. It is important, therefore, to know the crystallizing power for various temperatures of the glasses to be annealed, in order that a temperature may be chosen that will not induce devitrification. The choice is not so easily made as it was for molding purposes, for there is no definite lower limit of devitrification temperatures analogous to the upper limit that has been pointed out, and while there is for any glass a practical lower limit below which the power of crystallization or devitrification is negligible, this is, unfortunately, in the case of some glasses, a temperature at which rate of annealing is of like magnitude. At low temperatures devitrification is induced in a certain time at a certain temperature, in a shorter time at a higher temperature, and so on. It is

therefore desirable to know for any glass whether devitrification will be induced at any given temperature in a period of time which

TABLE 2.

Experiments on Devitrification of Certain Optical Glasses.[1]

Time. Hours.	Temperature °C.	Temperature °F.	Results.
	Barium Flint Glass.		
15.0	660	1220	No devitrification.
27.5	700	1292	No devitrification.
29.0	750	1382	No devitrification.
68.0	800	1472	No devitrification.
	Medium Flint Glass ($n_D = 1.62$) Crystals; SiO_2.		
1.0	650	1202	No devitrification.
12.5	650	1202	Slight surface film.
4.5	700	1292	No devitrification.
6.5	700	1292	Slight surface film.
23.5	700	1292	Marked surface film.
	Borosilicate Crown Glass. Crystals; SiO_2.		
14.5	660	1220	No devitrification.
27.5	700	1292	Surface devitrification.
4.5	750	1382	Surface devitrification.
8.0	750	1382	Surface devitrification.
2.3	800	1472	Surface devitrification.
20.6	800	1472	Surface devitrification.
	Ordinary Crown Glass. Crystals; SiO_2 and $CaSiO_3$.		
41.0	600	1112	No devitrification.
36.0	650	1202	No devitrification.
4.0	700	1292	Slight surface film.
6.5	700	1292	Surface film.
23.5	700	1292	Thick surface layer.
33.0	700	1292	Thick surface layer.
47.0	700	1292	Thick surface layer.

is long enough to give adequate annealing at that temperature. A fore-knowledge of both rates of devitrification and of rates of

[1] Temperature measurements by J. C. Hostetter. Identification of crystalline phases by N. L. Bowen.

annealing for various glasses is therefore requisite. It is plain, too, from the foregoing discussion, that glasses will be encountered in which fine-annealing and freedom from devitrification are mutually incompatible.[1] In such a glass every effort should be made to change the composition in such a manner as to increase the annealing rate or decrease the devitrification rate, or to accomplish both these results simultaneously. In making a change of composition a knowledge of the nature of the phases that separate is again desirable, precisely as it was for devitrification at other stages in the manipulation of the glass. Devitrification during annealing may take the form of the separation of spherulites or of minute crystals more evenly distributed that give a milky or dense, opaque glass. The identification of the crystals in the spherulites is usually readily accomplished and in the opaque glass one can frequently obtain a clue as to the nature of the crystals by observation of the relative refraction of crystals and glass. In milky glass one cannot determine the crystals, but intensification of the effect can frequently be obtained by raising a piece of the glass to a somewhat higher temperature. The larger crystals thus formed may then be identifiable.

In Table 2 the results are given of a study of devitrification of various glasses at these lower temperatures. It should be remarked that frequently the devitrification may take place only at the free surface of a piece of glass, but the reason for this greater freedom of devitrification at the surface is unknown.

Summary.

Devitrification of glass is the result of the tendency of the glass to reach the stable crystalline condition, and takes place whenever the glass is held for a sufficiently long period of time within the range of temperature where its crystallizing power is great. The various forms of devitrification in glass are discussed from this point of view and suggestions are made as to the principles that must be borne in mind in deciding upon modifications of

[1] It is perhaps worthy of note that certain opaque (devitrified) glasses that are used for ornamental purposes are clear when first cooled to the desired shape and become opaque only on reheating which accomplishes the double purpose of annealing and devitrification.

procedure or changes in composition that have as their object the avoidance of devitrification. Specific examples of the devitrification of optical glasses are given, together with determinations of the temperatures of devitrification and the crystalline phases separating.

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COMMUNICATED DISCUSSIONS.

W. S. WILLIAMS: The thanks of the glass technologists are due Dr. Bowen for his able exposition of some of the fundamental principles of physical chemistry applied to glass. It is to be regretted that the compositions of the glasses which devitrified are not given. They would serve as a guide and a warning in the manufacture of these types of glasses.

In my experience in the manufacture of optical glass at the Bureau of Standards, I have never experienced devitrification of light barium crown, $n_D' = 1.57$. All of the compositions used were compounded with a knowledge of ceramic chemistry and will be published in this JOURNAL. Of these, only one type tends to devitrify when the technic described in the above article is followed. This is the dense barium crown, $n_D = 1.60$. I have seen only two melts of this type devitrify during the melting stage. The composition of the first one was

	Per cent.
SiO_2	40.7
B_2O_3	6.2
ZnO	9.3
BaO	43.2
As_2O_3	0.6
	100.0

This batch was filled in sixteen hours at 1350° C and was closed and held at 1350° C for eight hours, during a fining period. When a proof was taken a slight scum was observed and skimmed off. Two hours later, however, a scum about 3 inches deep had formed.

This was also skimmed and about three inches of clear glass was taken out of the pot with the purpose in view of endeavoring to eliminate the nuclei, if possible. The temperature was raised 50° C to 1400° C. Three hours later, however, fully 6 inches of glass showed devitrification and the melt was abandoned. When cold the melt exhibited about 12 inches of dense, pure white opal glass on the surface and the rest of the glass was clear. Chemical analyses of the clear glass and opal glass demonstrated marked differences in their compositions. The analyses were as follows:

	Clear glass.	Opal glass.
SiO_2	37.88	44.67
BaO	42.36	38.02
ZnO	10.52	9.25
B_2O_3	9.31	8.46

A petrographic examination was baffling—due to the extremely fine state of the crystals. This was a case of devitrification occurring during melting and fining. In subsequent melts the difficulty was eliminated by the addition of Al_2O_3.

The second case of devitrification in dense barium crown, $n_D = 1.60$, occurred with a batch of the following composition:

	Per cent.
SiO_2	37.0
B_2O_3	5.0
K_2O	2.7
ZnO	7.8
BaO	47.0
As_2O_3	0.5

This batch was filled in 15 hours at 1400° C and fined for two hours. During a stirring period of 12 hours the temperature was gradually reduced to 1100° C. No devitrification was observed, but when the melt was cold spherulites were seen on only one side of the pot about 8 inches down from the surface. They extended about 6 inches from the side of the pot into the glass. These spherulites were determined under the microscope to be barium disilicate. With the exception of these few nodules the glass was good.

During molding and annealing dense barium crown, $n_D = 1.60$, of all compositions, devitrifies readily and must be molded in the shortest possible time. Sticking on a punty and heating in a glory hole is the most satisfactory method of molding, as the heat is more intense and the glass more uniformly heated than by other methods.

BUREAU OF STANDARDS,
PITTSBURGH, PA.

E. W. TILLOTSON: In this paper Mr. Bowen has made a noteworthy contribution to the subject of devitrification. As a natural consequence of his observations of the separation of crystalline material, mention is made in several places of the relation of devitrification to the production of translucent and opaque glasses. The writer would therefore like to inquire whether Dr. Bowen would exclude as possible causes of turbidity in glass the formation of "emulsions"[1] (glass in glass) or of "foams" (gas in glass).

MELLON INSTITUTE OF INDUSTRIAL RESEARCH,
PITTSBURGH, PA.

N. L. BOWEN: The compositions of the glasses on which we made devitrification experiments were not given in the article, because the original batches of Table 2, and of the ordinary crown and light barium crown in Table 1, had been used by the chemists of the Pittsburgh Plate Glass Company before the dat when the party from the Geophysical Laboratory was invited to cooperate in optical glass manufacture at the Charleroi plant. The officials of the Company have requested that these compositions should not be published. Changes were subsequently made in the formulas of some of these glasses, particularly in the light barium crown, which, on account of devitrification, was not satisfactory until its composition had been altered as indicated on page 271.

I have seen a sample of a scum formed on barium glass similar to that described by Mr. Williams though I was not present during the making of the melt itself. Under the microscope this scum was found to consist of glass with a cloud

[1] See for example, Guertler *Z. anorg. Chem.*, **40**, 225 (1904).

of minute crystals of silica in one of its low refracting forms, tridymite or cristobalite.

Evidently Mr. Williams' scum was identical, for a simple calculation shows that if one took 9 grams of material corresponding in composition with his "Clear Glass" and added thereto 1 gram of silica, one would obtain a material of the composition of his "Opal Glass." The continued formation of this scum as observed by Mr. Williams was therefore the result of the rising of these minute crystals of silica towards the surface. Whether the formation of these crystals is a true example of devitrification is questionable; indeed, it seems rather probable that they may represent completely recrystallized silica that had never completely dissolved because the melt was too slow. The fact that undissolved silica will rise through the glass in this manner is clearly demonstrated by Fig. 1 in my paper on "Identification of Stones."[1]

In reply to Dr. Tillotson, I would say that formation of emulsions and foams should not be excluded as possible causes of turbidity in glass, but in the turbid glasses that I have seen there seems little reason to believe that anything other than crystalline particles are the underlying cause. One can usually modify the treatment that renders a glass turbid in such a way (for instance, by prolonging the treatment) that the particles causing turbidity become sufficiently large for identification as crystal particles.

[1] THIS JOURNAL, 1, 598 (1918).

SOME PHYSICAL PROPERTIES OF AMERICAN COMMERCIAL PORCELAIN BODIES.[1]

By J. W. Wright and S. I. Sewell.

Introduction.

The purpose of presenting this work is to make possible the comparison of the physical properties of several commercial porcelain bodies used in the manufacture of table ware. It is desirable to have available physical constants relating to the mechanical strength and thermal properties of porcelain bodies; first, in order to establish data of general interest; second, in order to facilitate the replacing of materials now used by others. Such data is necessary if domestic clays are to be used in replacing those which are imported.

The work completed to the present time has afforded the following data for purposes of comparison:

1. Water content in the plastic state.
2. Drying shrinkage by volume.
3. Transverse strength in the dry state.
4. Compressive strength in the dry state.
5. Compressive strength in the fired state.
6. Vitrification behavior.

The Investigation.

Six commercial porcelain bodies were secured from potteries and numbered C-1, C-2, C-3, C-4, C-5 and C-8, respectively. These bodies were received in the plastic state. Although they had been packed with damp cloths, they were too stiff to work well on reaching the laboratory, except Body C-8, which was delivered the same day it was shipped from the pottery. The other bodies were brought, as near as possible, to the same consistency. Included with these bodies were two prepared in our laboratory. These laboratory mixtures were as follows:

[1] By permission of the Director, Bureau of Standards.

BODY NO. 163.

		Per cent.
Tenn. No. 9 ball clay		8.0
Georgia kaolin Florida kaolin Delaware kaolin N. Carolina kaolin	1/4 each	37.0
Feldspar		18.0
Flint		37.0

BODY NO. 175.

Tenn. No. 9 ball clay		5.87
Georgia kaolin Florida kaolin Delaware kaolin N. Carolina kaolin	1/4 each	38.28
Feldspar		17.71
Flint		36.30
Whiting ($CaCO_3$)		0.89
Magnesite ($MgCO_3$)		0.95

Body No. 163 was ground in a ball mill for a period of forty-eight hours, while body No. 175 was ground for only three hours.[1]

1. **Water Content in the Plastic State.**—The values (Table 1) represent the averages of the results on three test specimens and were computed in percentages of the dry weights. The weights of the briquettes were taken immediately after they had been made; they were then dried at 110° C and after cooling in a desiccator the dry weights were determined.

2. **Drying Shrinkage by Volume.**—The values (Table 1) represent the averages of the results on three test specimens and were computed in percentages of the dry volumes. Immediately after the specimens had been made they were immersed in kerosene and the volumes were determined in a volumeter of the Seger type. After drying at 110° C and cooling in a desiccator, the dry volumes were determined in a like manner.

3. **Transverse Strength in the Dry State.**—The values (Table 1) represent the average moduli of rupture in pounds per square inch of ten specimens broken on a transverse-strength testing-machine

[1] Riddle and McDanel, *J. Am. Ceram. Soc.*, 1, 620 (1918).

The specimens for this test were bars, 1″ × 1″ × 7″, shaped by pressing into a brass mold, using a piece of plastic body previously cut by a wire to as near the size of the mold as possible, pressing, and then cutting off the excess with a wire. The bars were dried at 110° C, cooled in a desiccator, and broken, From the dimensions of each specimen and the breaking load, the moduli of rupture were calculated by the use of the usual formula.[1]

4. Compressive Strength in the Dry State.—The values (Table 1) represent the averages of determinations on seven specimens, calculated in pounds per square inch. The specimens were $1^1/_8$″ cubes, cut from a plastic bar of clay which had been shaped in a manner similar to that used in making the transverse-strength bars. Before crushing, the test pieces were dried at 110° C, cooled in a desiccator, and two opposite sides made parallel and smooth by rubbing with sand paper.

5. Compressive Strength in the Fired State.—The values (Table 1) represent the higher results on one of two specimens and were computed in pounds per square inch. Cylinders for this test were made by forcing a column of clay through a die,

TABLE 1.

Body No.	Pounds per square inch.			Per cent water content.	Per cent volume drying shrinkage.
	Compressive strength in dried state.	Transverse strength in dried state.	Compressive strength in fired state.		
163		112	26,300	34.40	16.73
175		116	39,000	32.17	15.87
C-1	435	174	39,500	23.51	7.96
C-2	509	215	49,500	26.88	10.83
C-3	411	144	42,650	27.37	11.71
C-4	423	170	47,600	28.00	11.90
C-5	495	206	63,500	26.62	11.69
C-8	615	178	40,000	28.90	13.51
Average of the 6 commercial bodies	461	181	47,125	26.88	11.26

[1] Report of the Committee on Standards, *J. Am. Ceram. Soc.*, 1918, 40 (Jan.).

$1\frac{1}{4}''$ in diameter, and cutting the column into three-inch lengths. They were fired to cone 11 and held at the temperature at which this cone went down for a period of four hours. Cone 12 did not show any deformation under this heat treatment. The six commercial bodies showed zero absorption. After grinding the ends of each test cylinder parallel it was crushed in an Olsen testing-machine.

6. Vitrification Behavior.—The porosity and volume changes of the bodies and their firing ranges were determined by means of a draw-trial burn. Briquettes, $1\frac{1}{8}'' \times 1\frac{1}{8}'' \times 2''$ were made by forcing a column of the clay through a die and cutting to the desired length. The volumes of the dry briquettes were determined as before. They were placed in a muffle so that one specimen from each body could be drawn at the respective temperatures as shown in Table 2. The deformation of Orton cones at each drawing was also noted. The kiln was fired with natural gas and compressed air under oxidizing conditions. The rate of temperature increase was 20° C per hour for a period of three and one-half hours previous to the first draw and throughout the remainder of the burn. After each set of trials was drawn from the furnace it was placed in an auxiliary furnace, at low-red heat, and at the end of the burn was allowed to cool at the normal rate with the furnace. The dry weights and, after boiling under partial vacuum, the wet and suspended weights were then determined. From these data the porosities were calculated by the use of the Purdy formula.[1] The volumes of the burned pieces were determined and the changes in volume, or the burning shrinkages, were computed in percentages of the volumes of the unburned specimens.

When a body reached zero absorption it was considered matured. The volume shrinkage of a body should approach, but not necessarily reach, the maximum change when zero absorption is first reached. However, maximum shrinkage should not be reached prior to obtaining zero absorption. If a body shows, on reaching zero absorption, a decrease in shrinkage from its maximum, it is likely that the point of over-firing has been

[1] R. C. Purdy, Illinois Geol. Survey, *Bull.* **9**.

TABLE 2.

Temperature ° C.		1160.	1180.	1200.	1230·	1260.	1290.	1320.	1350.	1380.	1410.	1440.
Cone deformation.		4 flat.	7 flat.		11 started.	12 ¾ down.	13 ¼ down.	13 flat.		15 down.	16 flat.	17 flat.
Body C-1	% Porosity	18.98	15.10	8.13	7.78	1.76	0.03	0.00	15.25	14.30		
	% Volume burning shrinkage	18.40	21.50	25.00	28.50	30.80	30.82	29.65	18.52	14.82		
Body C-2	% Porosity	25.31	18.45	9.63	5.23	0.08	0.00	0.00	12.65	10.60		
	% Volume burning shrinkage	14.75	20.55	25.10	30.50	33.05	31.80	28.55	21.25	17.00		
Body C-3	% Porosity	27.70	17.85	9.38	4.00	0.00	0.07	18.00	18.80	21.90		
	% Volume burning shrinkage		22.50	28.88	34.55	33.30	25.05	16.73	14.22	10.42		
Body C-4	% Porosity	21.45	16.02	8.86	2.66	0.07	0.07	0.38	14.05	10.42		
	% Volume burning shrinkage	19.95	23.05	27.80	31.70	33.15	31.35	24.65	18.50	14.58		
Body C-5	% Porosity	27.30	20.55	11.57	4.42	0.13	0.04	7.37	11.80	8.77		
	% Volume burning shrinkage	13.59	19.88	26.35	33.00	33.90	30.30	21.92	18.82	15.70		
Body C-8	% Porosity	14.50	9.23	2.47	0.00	0.67	3.35	3.16	12.40	8.32		
	% Volume burning shrinkage	23.40	28.03	31.40	33.25	30.25	20.35	19.25	16.70	15.02		
Body 163	% Porosity			15.82	10.40	0.04	0.00	0.00	0.00	0.00	4.15	1.10
	% Volume burning shrinkage			25.20	30.50	35.00	36.55	36.00	36.30	33.12	22.87	23.05
Body 175	% Porosity			8.00	6.57	2.56	0.56	0.04	0.08	0.07	2.35	4.50
	% Volume burning shrinkage			32.40	33.15	24.10	34.30	34.75	32.60	21.75	21.00	21.05

reached. The volume changes give, undoubtedly, better indications of the firing range of a body—since they indicate over-burning in a much more decisive manner than do the porosity changes. Bodies usually show a tendency to expand before an increase in porosity is observed.

Summary of Results.

The data shown in Table 2 are plotted as curves (Figs. 1, 2 and 3) which can be studied to better advantage. Each diagram shows two commercial bodies in comparison with the two labora-

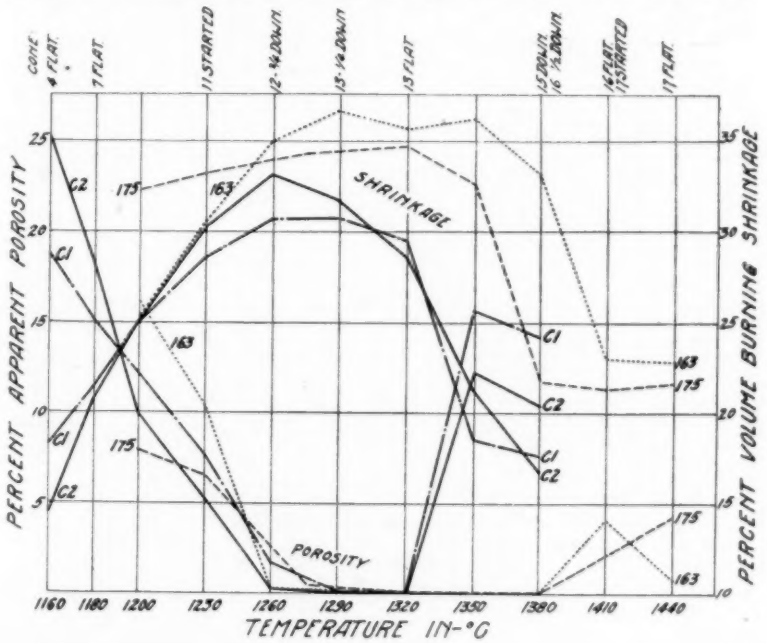

FIG. 1.

tory bodies. Body No. 163 was fired in the same draw-trial burn with the commercial bodies. Body No. 175 had been burned previously, but under similar conditions.

Body C-1 (Fig. 1) reaches maximum shrinkage and approaches zero absorption at 1260° C, or the equivalent to a heat treatment of cone 12, ¾ down. Over-burning of this body is not in evi-

dence at or below a temperature of 1320° C, thus showing it to possess a firing range extending over an interval of 60° C.

Body C-2 (Fig. 1), like Body C-1, reaches maximum shrinkage and approaches zero absorption at 1260° C. The test pieces show a slight expansion in the two following draws. The firing range can be considered to extend over a temperature interval of 60° C.

The laboratory bodies, Nos. 163 and 175, reached zero absorp-

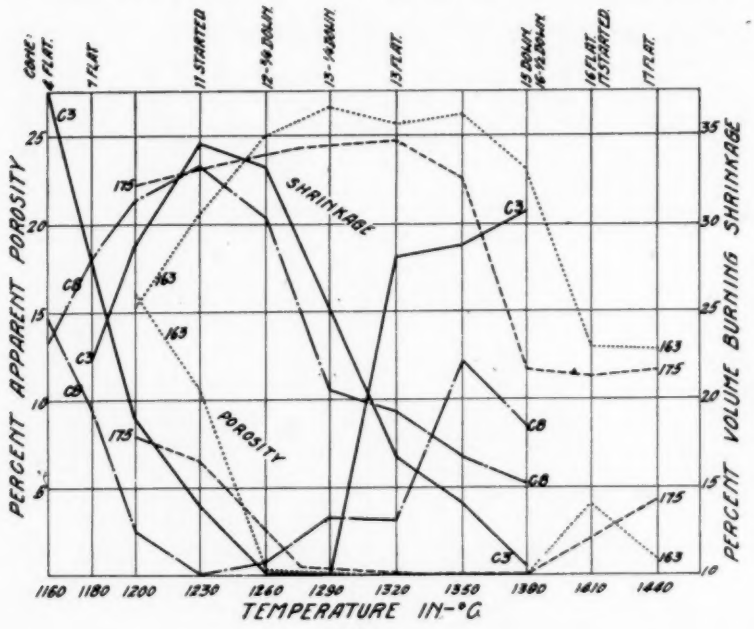

FIG. 2.

tion and approached maximum shrinkage at 1260° C and 1275° C, respectively. The shrinkage and porosity curves show that these bodies have much longer firing or maturing ranges than the commercial bodies. Upon comparing the shrinkage curves, body No. 175 is found to show over-burning before body No. 163. This is to be expected because of the greater content of alkaline earth fluxes of body No. 175.

Body C-3 (Fig. 2) develops its maximum shrinkage at 1230° C

(cone 11 started), but zero absorption is not obtained until 1260° C is reached, whence swelling has begun. At 1290° C, the body still shows zero porosity, but the swelling has been excessive. The firing range of this body is very short.

Body C-4 (Fig. 3) shows maximum shrinkage and zero absorption at 1260° C. At 1290° C a slight but not excessive expansion

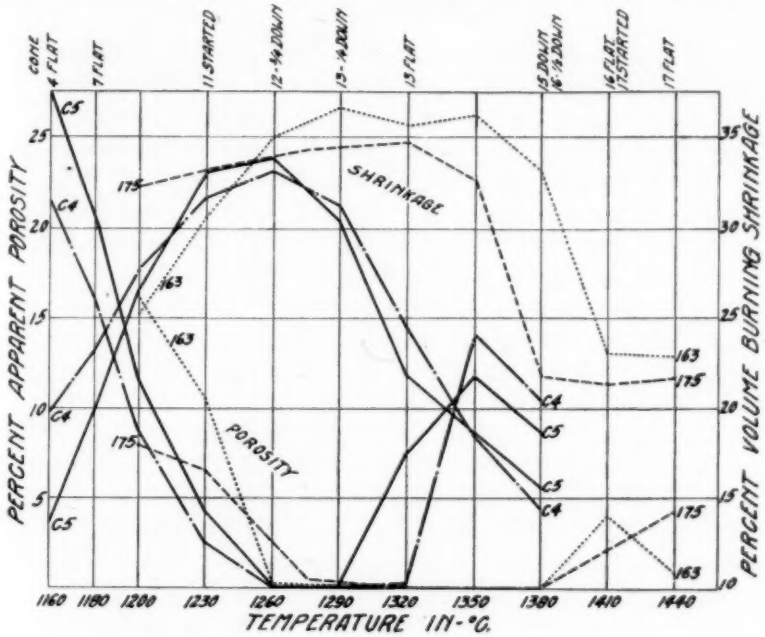

FIG. 3.

occurs. The burning range of this body, according to the draw-trial burn, is approximately 30° C.

Body C-5 (Fig. 3) shows approximately the same burning characteristics as body C-4.

Body C-8 (Fig. 2) shows burning maturity at a lower temperature than any of the other bodies. According to the draw-trial burn, maturity is reached at 1230° C, or the equivalent to a heat treatment of cone 11 started. It shows expansion and an increase in porosity at the next draw, 1260° C. The body has a very short firing range.

The fact that all of the commercial bodies had zero absorptions at cone 11 in the longer heat treatment and not until cone 12 was $^3/_4$ down in the draw-trial burn, in all cases except with C-8, which reached non-absorbent vitrification at cone 11 started, may be attributed to the difference in the rate of temperature increase and its effect upon the fluxes other than feldspar.

Conclusions.

The numerical results obtained in this work are of interest since the determinations were made upon typical commercial bodies which are the result of years of practical experience. They show decided similarity. The strengths of the bodies in the dried state and the strengths of the fired porcelains show no radical differences. There is no evidence that the crushing strength in the dried state is a criterion of the fired strength.

The average figures for the different factors of the six commercial bodies should be of general interest. It will be observed, also, that the water contents and hence the drying shrinkages of the laboratory bodies are higher and the transverse strengths of the dried bodies lower than the corresponding values for the commercial porcelains. Similarly, the compressive strength in the fired state of body No. 163, containing no alkaline-earth fluxes, is the lowest of the series. On the other hand, the temperature ranges at non-absorbent vitrification of the laboratory bodies are longer than those of the pottery bodies—which would indicate the desirability of further work along these lines.

The writers desire to express their thanks to the manufacturers of table-ware porcelain who have coöperated in this work by furnishing the samples of prepared bodies for the tests.

Bureau of Standards,
Pittsburgh, Pa.

EXPERIMENTS IN DEAD-BURNING DOLOMITE.[1]

By H. G. Schurecht.

Introduction.

Magnesite and dolomite are used for linings in furnaces where basic refractories are necessary to resist the corrosive action of basic slags. Some of the uses are as follows:

1. Reverberatory lead-refining furnaces. Lead cupeling-furnaces, where the slag consists chiefly of basic oxides. Crucibles for lead blast-furnaces.
2. Copper converters and copper reverberatory furnaces.
3. Basic open-hearth and Bessemer furnaces.
4. Crucibles for melting metals.

In 1914, 120,583 tons of calcined magnesite[2] were imported into the United States, chiefly from Austria-Hungary. Owing to the war no magnesite was imported into this country in 1916. American manufacturers were, therefore, forced to use California and Canadian magnesites, which, owing to their high degree of purity, were not as satisfactory as the Austrian magnesite—which contains sufficient iron oxide to render it suitable for the manufacture of refractories.

Owing to the fact that dolomite deposits occur nearer to the steel centers, and to its lower cost, experiments were undertaken in dead-burning some Ohio dolomites which are extremely pure and almost as refractory as magnesite.

Some of the difficulties encountered in the use of calcined dolomite for the manufacture of refractory products are as follows:

1. It does not stand storage well. This is due largely to the fact that the raw materials are too pure before calcination—in which case the lime air-slakes readily.

2. It lacks bond when used in a furnace and therefore has a short life. This is also due to the high degree of purity which

[1] By permission of the Director, U. S. Bureau of Mines.

[2] C. G. Yale and H. S. Gale, "Magnesite in 1916," U. S. Geol. Sur. Mineral Resources of the U. S., Part II, pp. 391–401 (1918).

does not permit the dolomite to bond together as it would if some impurities were present.

Previous Work.

A large number of patents have been issued within the past few years on dead-burning the purer grades of magnesite and dolomite.

The methods employed may be arranged in three general groups, as follows:

1. By mixing an impurity[1] with the finely-ground rock and

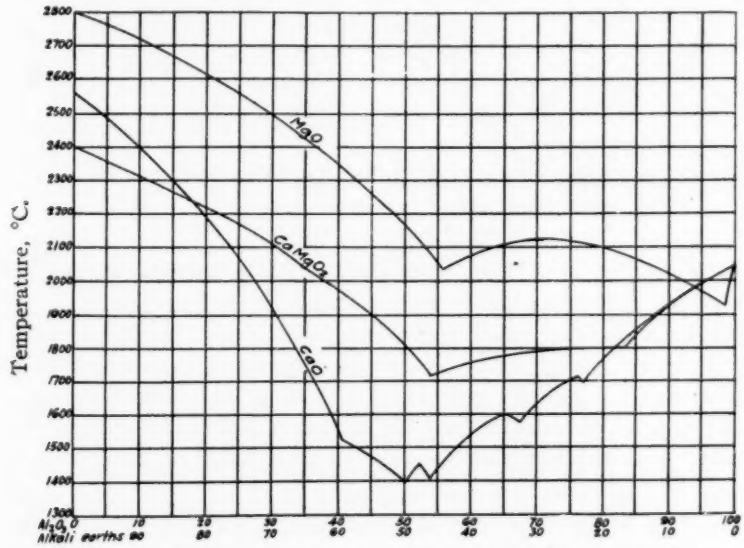

FIG. 1.—The effect of Al_2O_3 on the fusion of CaO, MgO and $CaMgO_2$.

calcining the mixture in a rotary kiln. The impurities recommended are: silica, iron oxide, roll scale, flue dust, alumina, chromium oxide, manganese oxide, cobalt oxide, nickel oxide, borax, calcium chloride, magnesium chloride and sodium chloride.

2. Another method, used by Jones,[2] consists in mixing 90

[1] G. L. Davison, U. S. 792,382, June 20, 1905, "Dead-burning of Magnesite." C. B. Stowe, U. S. 1,205,056, Nov. 14, 1916, "Dead-burning of Magnesite." J. O. Handy and R. M. Isham, U. S. 1,270,818, July 2, 1918, "Dead-burning of Dolomite." S. B. Newberry, U. S. 1,267,686, May 28, 1918, "Dead-burning of Dolomite."

[2] Fred A. Jones, U. S. 151,535, Jan. 1, 1918, "Process of Producing a Furnace Lining with Dolomite."

parts coarsely screened dolomite, 2–8 mesh, with 10 parts flue dust and burning the mixture in a rotary kiln. This product is then used for lining furnaces.

3. The third method used is to separate the MgO from dolomite, $MgCa(CO_3)_2$. It has been found[1] that MgO can be more easily dead-burned than CaO—owing to the fact that CaO has a higher tendency to combine with water and slake. This separation is accomplished in two different ways: one method[2] is by

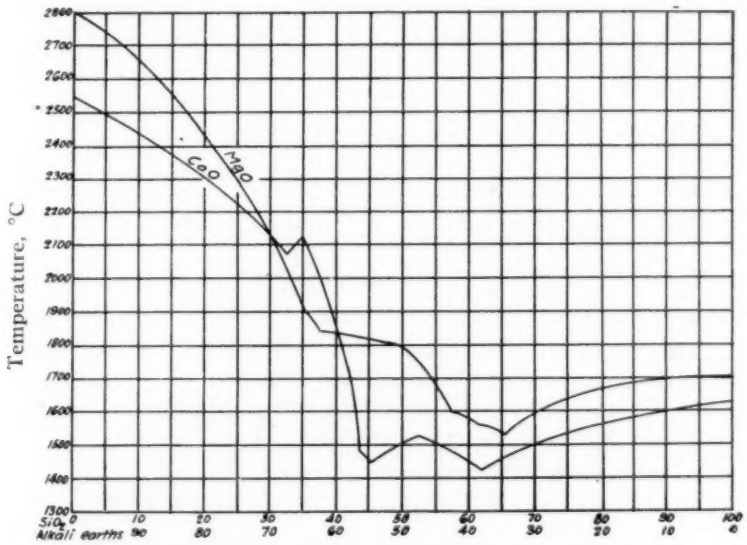

FIG. 2.—The effect of SiO_2 on the fusion of MgO and CaO.

crushing the dolomite and heating it to 950° F. This temperature decomposes the $MgCO_3$ entirely but allows the $CaCO_3$ to remain in the crystalline form. The MgO is then removed with water or by means of a pneumatic separator; another method[3]

[1] A. Wasum, "The Effects of Some Furnace Conditions on Basic Refractories Used in Melting Operations." *Trans. Eng. Ceram. Soc.*, 16, 324–326 (1916–17).

[2] Ardon M. Mitchell, U. S. 1,273,110, July 16, 1918, "Process for Obtaining MgO from Dolomite."

[3] J. O. Handy and R. Isham, U. S. 1,270,819, July 2, 1918, "Separation of Lime from Dolomite."

is to decompose the $CaCO_3$ as well as the $MgCO_3$. Water is then run over the calcined mixture and, owing to its greater solubility, the lime is carried off first. This process is continued until all but 3–10 per cent CaO has been removed.

The effect of Al_2O_3 and SiO_2 on the softening points of MgO and CaO was studied by Rankin and Merwin.[1] It was found (see Figs. 1 and 2) that SiO_2 had a much greater fluxing action on the oxides of the alkali earths than Al_2O_3.

Following are the analyses of five typical commercial refractories prepared from magnesite or dolomite:[2]

	No. 1. %	No. 2. %	No. 3. %	No. 4. %	No. 5. %
CaO	2.60	49.10	0.45	6.00	15.0
MgO	89.20	34.36	87.35	75.00	70.0
SiO_2	5.60	7.23	6.60	7.00	5.5
Fe_2O_3 }	1.40	5.31	4.30	12.00	8.5
Al_2O_3 }		2.80			
Loss on ignition	1.20	1.11	1.30	....	0.5

Outline of Investigation.

The following impurities were added in varying percentages to a dolomite from Cedarville, Ohio, which had previously been screened through an eight-mesh sieve:

1. Coal Tar
2. Flue dust
3. Iron ore
4. Basic open hearth slag
5. Blast-furnace slag
6. Bedford shale
7. Kaolin
8. Roll scale
9. Calcium chloride

The analysis of Cedarville dolomite is given by the Ohio Geological Survey[3] as follows:

[1] G. A. Rankin and H. E. Merwin, "The Ternary System, $MgO.Al_2O_3.SiO_2$." *Am. J. Sci.*, **45** (1918); G. A. Rankin and H. E. Merwin, "The Ternary System $MgO.Al_2O_3.SiO_2$," *J. Am. Chem. Soc.*, **38** (1916).

[2] No. 1. "Dead-burned California Magnesite," U. S. Magnesite Corporation, 39 Cortlandt Street, New York, N. Y.

No. 2. "Dolomite," Kennedy Refractory Co., Union Arcade, Pittsburgh, Pa.

No. 3. "U. S. Magnesite," E. Kaufmann & Co., Pittsburgh, Pa.

No. 4. "Ferro-magnesite," Refractory Magnesite Corp., New York City.

No. 5. "Dead-burned Magnesite," National Sales Co., Cincinnati, Ohio.

[3] E. Orton and S. V. Peppel, "Limestone, Lime and Sand-Lime Brick," Ohio Geol. Sur., Fourth Series, *Bulls.* **4** and **5**, 152–153 (1906).

	Per cent.
$CaCO_3$	53.95
$MgCO_3$	44.62
SiO_2	0.58
Al_2O_3	0.57
	99.72

Briquettes of the various mixtures were molded and calcined at cone 18 in a Hoskins electric furnace. Immediately upon being taken from the furnace they were weighed and after standing in air, in order to test their air-slaking behavior, they were reweighed after the following intervals: 2, 5, 10, 18, 28, 38, 50,

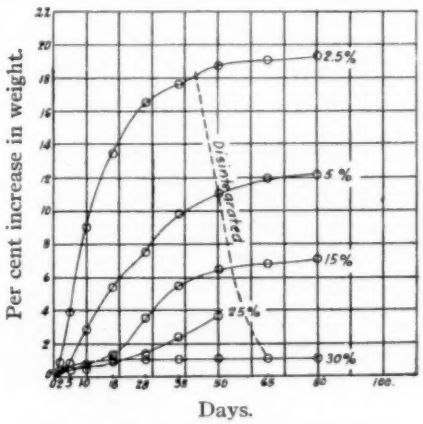

FIG. 3.—The effect of flue dust on the rate of slaking of dolomite, after burning to cone 18.

65, 80, 100 and 125 days, to determine the increase in weight. The point at which the briquettes disintegrated and no longer had mechanical strength was also noted.

In order to determine the effect of size of grain of the raw dolomite on the ease of dead-burning, the dolomite was screened through 4-, 8-, 20- and 40-mesh sieves. Varying percentages of iron ore were added to the dolomite thus screened, and the mixtures calcined to cone 18. The rate of absorption of water and the time necessary for the disintegration of the briquettes was then determined.

The screen analyses of the ground dolomite used were as follows:

Size of grain.	Size of openings in inches.	4 mesh.	8 mesh.	20 mesh.	40 mesh.
4–10	0.25 –0.005	58.80	14.65	...	...
10–20	0.065 –0.0328	18.70	33.82	0.30	...
20–35	0.0328–0.0168	9.50	19.91	34.36	1.96
35–48	0.0168–0.0116	2.25	5.98	12.40	19.50
48–65	0.0116–0.0082	1.95	5.22	12.00	17.10
65–100	0.0082–0.0058	1.88	4.92	8.28	15.80
100–150	0.0053–0.0041	0.71	3.42	4.72	9.10
150–200	0.0041–0.0029	2.24	6.58	11.80	14.25
Through 200	Through 0.0029	3.67	6.04	15.82	22.32

In order to determine the effect of the fluxes on the refractoriness of the dolomite the softening points were also determined.

Results of the Work.

Coal Tar.—A mixture of 10 parts coal tar and 90 parts dolomite was calcined to cone 18 under oxidizing conditions and also

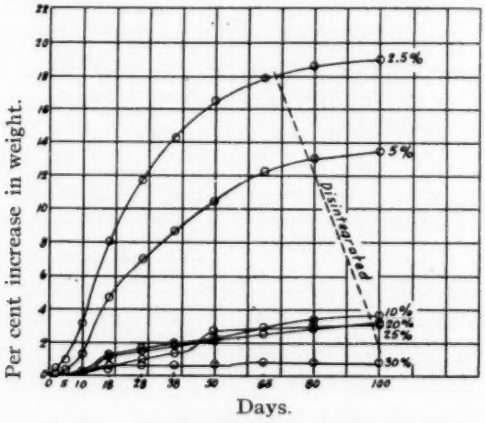

FIG. 4.—The effect of iron ore on the rate of slaking of dolomite after burning to cone 18.

under reducing conditions (secured by packing in graphite). After calcination it was found that the sample which had been calcined under oxidizing conditions disintegrated readily in water

while that which was calcined in graphite did not disintegrate after standing in water for two months. The latter material, however, was very porous and the addition of some flux would be necessary to produce a brick which would be impervious to slag.

Flue Dust.—For the results secured with flue dust, see Figs. 3, 10 and 11. When calcined, the mixture had a dark brown color

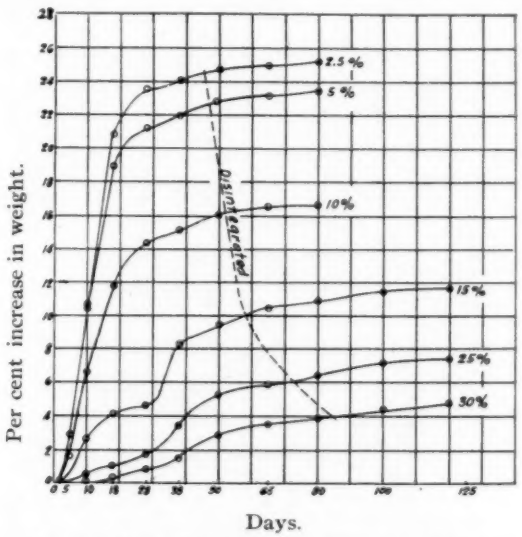

FIG. 5.—The effect of basic open hearth slag on the rate of slaking of dolomite after burning to cone 18.

and, in some cases, showed dusting.[1] This dusting was due to conversion of the beta to the gamma form of calcium orthosilicate, $2CaO.SiO_2$, which is formed at 675° C in cooling and is accompanied by an increase in volume of 10 per cent. This volume change shatters the material into a fine dust and sometimes breaks off big pieces from the sintered dolomite. It would appear that this would be a serious factor in causing spalling of dolomite brick made from a mixture of this kind.

[1] G. A. Rankin, "The Ternary System, $CaO—Al_2O_3—SiO_2$," *Am. Jour., Sci.*, **39**, 7–8 (1915).

The mixture made by calcining the mixture of 30 parts flue dust and 70 parts dolomite disintegrated after standing in air for 65 days. This mixture had a softening point of cone 31+.

Iron Ore.—For the results secured with iron ore, see Figs. 4, 10 and 11. The briquettes when burned had a brown color and showed very little dusting. It is evident that free silica, when added to dolomite in amounts capable of forming the orthosilicate, causes dusting, so it appears that the silica was held in

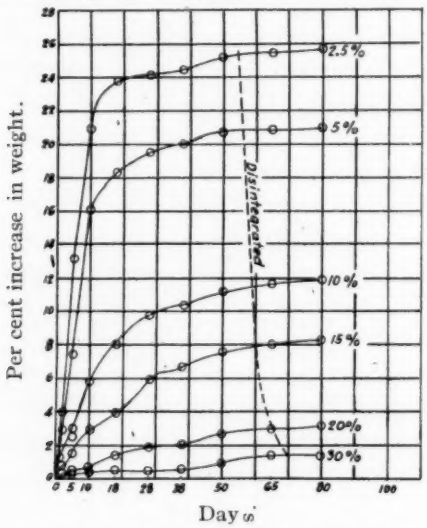

FIG. 6.—The effect of blast furnace slag on the rate of slaking of dolomite after burning to cone 18.

combination with the iron in this case and very little dusting resulted.

Mixtures made by calcining 30 parts of iron ore with 70 parts of dolomite had not disintegrated at the end of 100 days and had a softening point of cone 31−.

Basic Open Hearth Slag.—In Figs. 5, 10 and 11 are given the results secured with basic open hearth slag. The briquettes had a black color and showed some dusting. The mixture made by calcining 30 parts of slag with 70 parts of dolomite had a softening point of cone 31+ and disintegrated at the end of 85 days

Blast Furnace Slag.—The results secured with blast furnace slag are shown in Figs. 6, 10 and 11. The calcined briquettes had a white color and dusted excessively. This was undoubtedly due to the high silica content which was conducive to the orthosilicate formation in this slag.

The mixture made by calcining 30 parts of blast-furnace slag

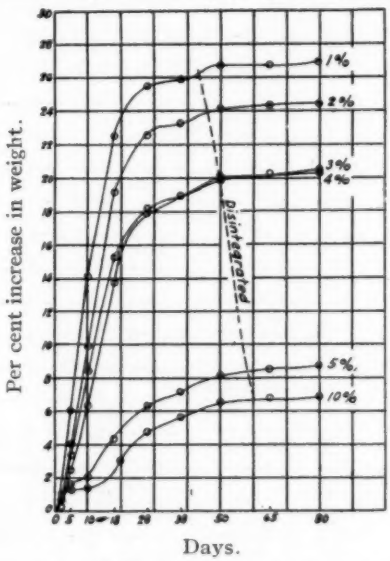

FIG. 7.—The effect of shale on the rate of slaking of dolomite after burning to cone 18.

with 70 parts of dolomite disintegrated in a comparatively short time, 70 days.

Bedford Shale.—The calcined briquettes containing shale and dolomite had a buff color and showed excessive dusting. This was also due to the high silica content of the shale—forming the orthosilicate with lime. Those briquettes containing the highest per cent of shale showed the most dusting.

The mixture prepared by calcining 10 parts of shale with 90 parts dolomite disintegrated at the end of 60 days (see Figs. 7, 10 and 11). The fluxing effect of silicious materials, like shale, seemed to decrease the refractoriness to a greater extent than the

addition of iron oxide—the mixture prepared by calcining 10 parts shale with 90 parts dolomite having a softening point of cone 31+.

Georgia Kaolin.—The calcined briquettes containing kaolin and dolomite had a cream color and showed less dusting than the mixture containing shale. The body burned dense and hard and if used for brick would be impervious to slag penetration. The mixture prepared by calcining 10 parts kaolin with 90 parts

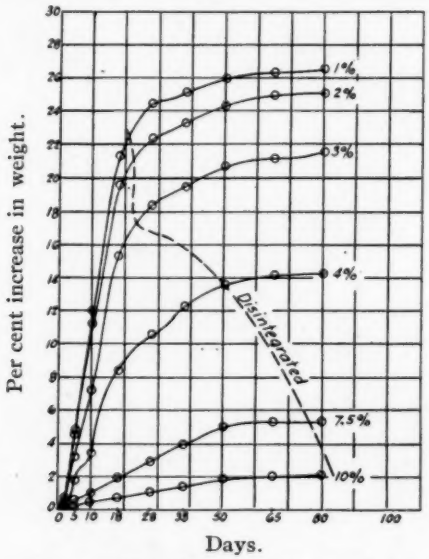

FIG. 8.—The effect of kaolin on the rate of slaking of dolomite after burning to cone 18.

dolomite disintegrated at the end of 85 days (see Figs. 8, 10 and 11). This mixture had a softening point of cone 31. When less than 3 per cent kaolin was used, the briquettes disintegrated in a comparatively short time, but where more was used there was a large increase in this time as is shown by the abrupt break in the disintegration curve.

Roll Scale.—For results secured with roll scale see Figs. 9, 10 and 11. The calcined briquettes in this case had a brown to

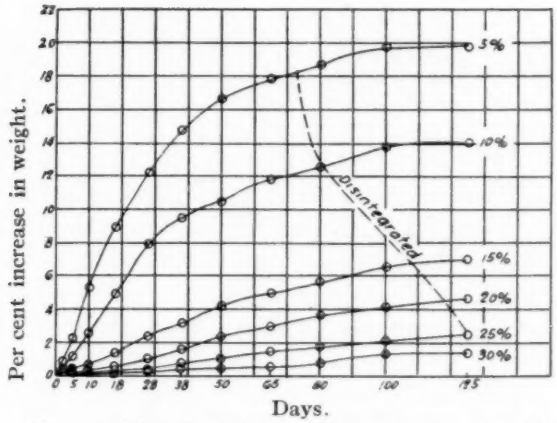

FIG. 9.—The effect of roll scale on the rate of slaking of dolomite after burning to cone 18.

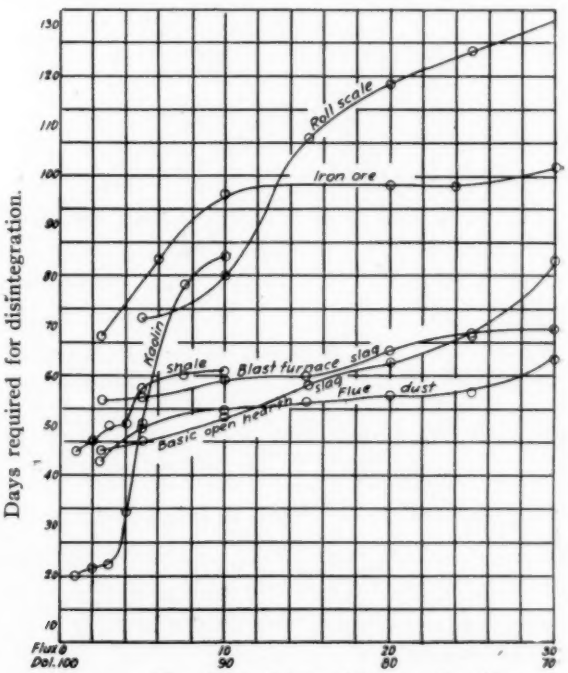

FIG. 10.—The effect of impurities on the time of disintegration of dolomite after burning to cone 18.

black color and very little dusting was noted—this being due to the high iron content of the roll scale. The mixture prepared by calcining 30 parts roll scale with 70 parts dolomite was not disintegrated at the end of 125 days—this mixture standing up better than any of the others (see Fig. 7).

Calcium Chloride.—A mixture of 10 parts calcium chloride and 90 parts dolomite was calcined to cone 14. The product had a buff color, good mechanical strength, and was very resistant

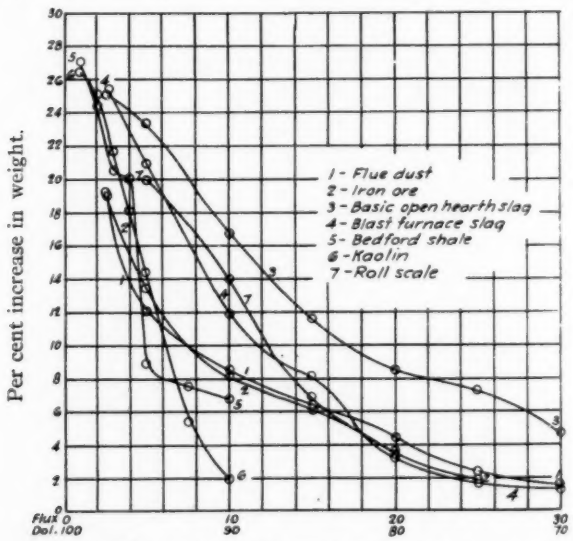

FIG. 11.—The effect of impurities on the increase in weight in air of dolomite after burning to cone 18.

to slaking. It, however, was very porous and if used without a flux would have low resistance to the penetration of slag.

Effect of Size of Grain on the Ease of Dead-Burning Dolomite.

The effect of size of grain on the ease of dead-burning was studied by screening the dolomite through 4-, 8-, 20- and 40-mesh sieves before calcination. For the results see Fig. 12. It appears that the coarse material passed through 4- and 8-mesh stood up longer than the dolomite screened through a 20-mesh

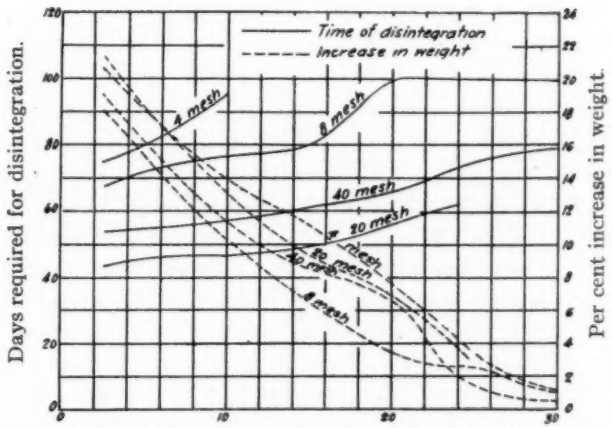

FIG. 12.—The effect of size of grain on the time of disintegration and increase in weight of dolomite in air after burning to cone 22.

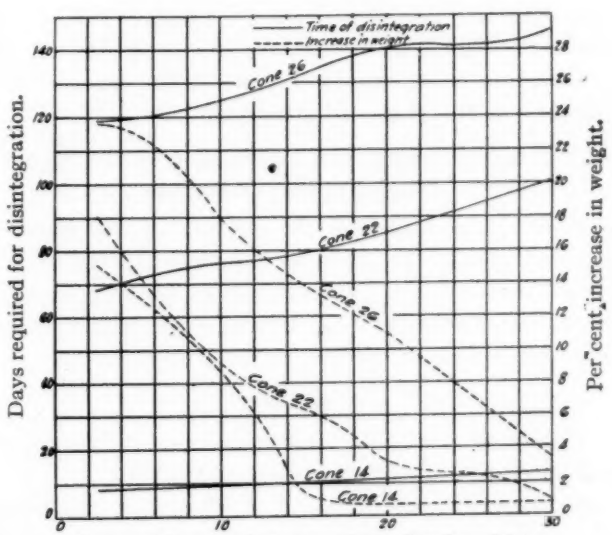

FIG. 13.—The effect of burning temperature on the time of disintegration and increase in weight in air of dolomite after calcination.

sieve, while the fine dolomite, screened through a 40-mesh sieve, stood up better than that screened through a 20-mesh sieve.

It appears, therefore, that the best results are obtained by grinding dolomite extremely coarse, through 4-mesh, or fine, through a 40-mesh sieve. In the first case a coating is probably formed about the individual grains. This coating protects the centers of the grains which are high in the purer CaO. Where no further fine grinding is necessary, as is the case when granular dolomite is used for basic linings, it would seem that this material would be satisfactory and have the advantage over the finely-ground dolomite in that the cost of grinding would be less. On the other hand, if this material were finely ground and mixed with water, as is done in making brick, it would crack in drying—owing to the slaking of the uncombined lime. For such purposes finely grinding the dolomite with iron oxide before calcination would be preferable because the dead-burning would be uniform throughout the material.

It is claimed by the users that domestic magnesite, which is very pure, lacks bond when used for furnace linings and soon crumbles. It would seem that the coarse grains of dolomite, coated with iron oxide, would stay set in the furnace—owing to the tendency of the grains to stick together.

Effect of Temperature of Calcination on the Ease of Dead-Burning Dolomite.

The effect of temperature of calcining on the ease of dead-burning was studied by burning to cones 14, 22 and 26. In every case the increased temperature of burning increased the number of days necessary for disintegration and decreased the maximum absorption of the briquettes, (see Fig. 13).

Summary.

Roll scale seems to be very effective in dead-burning dolomite without decreasing its refractoriness too much.

It was found that the addition of impurities containing silica caused dusting in the calcined material—due to conversion of the beta $2CaO.SiO_2$ to gamma $2CaO.SiO_2$. This was most pronounced when blast-furnace slag or shale were used and was

noticed to a lesser extent when flue dust, kaolin or basic open hearth slag were used. Mixtures containing roll scale or iron ore showed the least dusting.

It was found that a large percentage of iron oxide (20–30 per cent with 80–70 per cent dolomite) may be used without decreasing the refractoriness of the material below cone 31. Impurities which are silicious in character, like kaolin, decrease the refractoriness to a much greater extent. For instance, a mixture made by calcining 10 parts kaolin with 90 parts dolomite had a softening point of cone 31.

When dolomite is mixed with tar, packed in graphite, and burned to cone 18, it becomes very resistant to slaking. If it is not packed in graphite during the burning it slakes easily.

When dolomite is mixed with 10 parts calcium chloride and burned to cone 15 it becomes very resistant to the slaking action of water.

It was found that dolomite ground extremely coarse (through 4- or 8-mesh), or fine (through 40-mesh), was easier to dead-burn than when screened through 20-mesh. The coarse material, however, if reground, does not resist slaking as well as the 40-mesh material.

Increasing the burning temperature increases the resistance of the dolomite mixtures to disintegration, as would be expected.

In conclusion, the author wishes to acknowledge his indebtedness to Mr. R. T. Stull for his assistance in the above work.

BUREAU OF MINES,
MINING EXPERIMENT STATION,
COLUMBUS, OHIO.

THE COMPARATIVE VALUE OF KNEADING AND PUGGING IN THE PREPARATION OF PORCELAIN BODIES.

By L. E. Barringer and Chester Treischel.

Introduction.

Proper preparation of pottery mixtures is an important step in the process where the highest degree of excellence and uniformity is required. The several ingredients must not only be thoroughly mixed but the resultant body must be of uniform consistency in order to produce uniformity from piece to piece and should be free from cracks, air-pockets, and laminations which all produce imperfections in the finished ware.

Blunging and agitating mix the ingredients of pottery bodies but there is a tendency toward segregation in the filter-pressing, the lighter particles passing to that part of the filter-press cake farthest from the slip inlet and the heavier particles tending to concentrate nearest the feed hole.

In reducing filter-press cakes to the proper consistency for forming the ware, it is desirable to use an apparatus which both kneads and mixes and at the same time leaves the mass comparatively free from imperfections or air-inclusions. For reducing filter-press cakes to the desired consistency, two machines have been in use for many years, namely, the pug mill and the kneading- or rolling table.

The pug mill is an excellent mixer and works rapidly but tends to leave laminations where the knives and augers pass through the putty-like mass. Pug mill designers have studied this question for years and have succeeded in considerably reducing the amount of lamination by modifying the design of the augers; by special lubrication of the die or nozzle; by changing the shape of the pug mill barrel, etc., but still the tendency toward lamination remains as an inherent fault in this type of machine.

The rolling or kneading table has been used abroad for some years and has recently been described in connection with the

preparation of electrical porcelain bodies in France,[1] but has not been used to any considerable extent in this country—more because of its limited capacity than because of its not having any particular merit.

Theoretically, such a type of machine would not be expected to

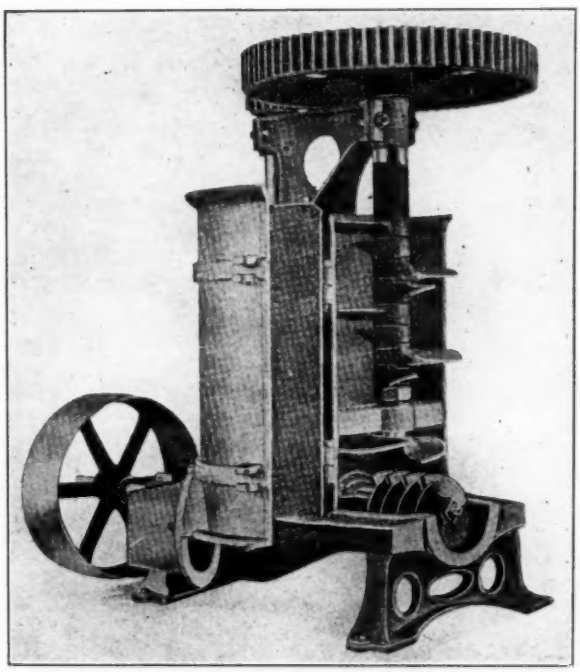

FIG. 1.—Pugging machine.

mix as well as a pug mill but would be expected to leave the mass more free from imperfections, both through not itself introducing such imperfections and also by handling the material in such a way as to expel more thoroughly any air which might be present in the mass—as the result of simply batting down filter-press cakes of irregular surfaces.

[1] Revue Generale de l'Electricite," 1, No. 2, p. 60.

Experimental.

Desiring to obtain first-hand knowledge of the comparative values of the pug mill and kneading table, particularly for preparing electrical porcelain bodies, the authors, together with Mr.

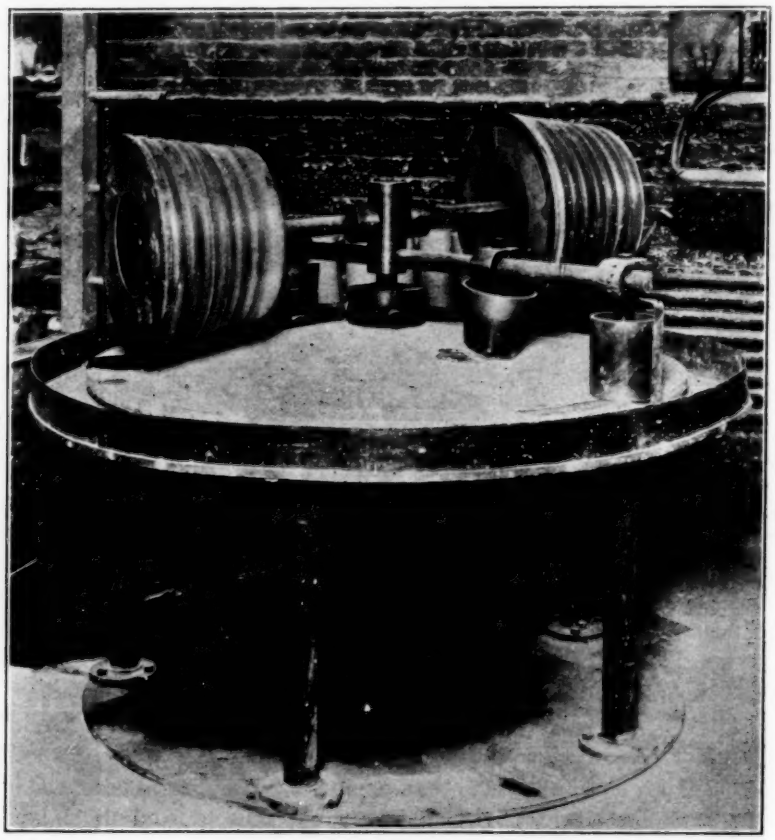

FIG. 2.—Kneading Machine.

F. Cermak, of the General Electric Company, set about trying both machines in the Porcelain Department of the General Electric Company at Schenectady, N. Y.

The type of pug mill used is shown in Fig. 1 and represents the machine used regularly in the preparation of porcelain bodies.

The kneading table used is shown in Fig. 2 and is one constructed by the General Electric Company to duplicate a French machine of the type commonly employed in European potteries.

Since the air content of the product of each machine can be taken as an indication of the condition inside the blanks, it was decided to use Spurrier's method[1] for obtaining the amount of entrapped air. Small samples about 30.0 cc. in volume were taken from the edges and from the centers of all blanks. These blanks, in turn, were taken from hard, medium, and soft bodies—the designation in each case referring to the workable condition of the body.

The data presented in Table 1 are averages of a large number of determinations—the actual testing covering a period of two months.

TABLE 1.

Machine.	Consistency of body.	Sample.	Average % air (by volume).
Pug mill No. 1		Interior	29.8
Pug mill No. 1		Edge	29.6
Pug mill No. 2		Interior	31.1
Pug mill No. 2		Edge	29.2
Kneading Table	Hard body—20 min.	Interior	25.6
Kneading Table	Hard body—20 min.	Edge	25.9
Kneading Table	Medium body—20 min.	Interior	27.5
Kneading Table	Medium body—20 min.	Edge	27.8
Kneading Table	Soft body—20 min.	Interior	28.3
Kneading Table	Soft body—20 min.	Edge	30.6
Kneading Table	Hard body—40 min.	Interior	29.5
Kneading Table	Hard body—40 min.	Edge	28.1
Kneading Table	Medium body—40 min.	Interior	27.4
Kneading Table	Medium body—40 min.	Edge	27.0
Kneading Table	Soft body—40 min.	Interior	32.1
Kneading Table	Soft body—40 min.	Edge	31.0

[1] *J. Am. Ceram. Soc.*, 1, 710 (1918).

Conclusions.

The results of these tests together with the conclusions which have been drawn are:

1. The center of the pug-mill blank contains more air than the edge, this being due to the greater pressure on the blank where it comes in contact with the die.

The center of the kneading-table blank may or may not contain *less* air than the edge, according to the length of time of kneading and to the amount of water contained in the body which is being tempered—a hard body contains less water than a soft one. Hard or medium bodies on 20-minute runs and medium bodies on 40-minute runs gave the most consistent results.

2. The kneading table is a more efficient air-remover than the pug mill. This is evidenced by a comparison of the data on pug mill body No. 1 and kneading table, hard body, 20-minute run—the bodies in this case being identical. However, a continued kneading for 40 minutes does not produce the desired effect, since air seems to be re-incorporated in the blank. This will be evident from a comparison of pug mill body No. 1 and the kneading table, hard bodies, 20 and 40-minute runs.

3. The kneading table seems to be most efficient on medium and hard bodies and when run for a period of 20 minutes. An average of the specific gravity and porosity determinations of all runs on the kneading table compared with the average for the pug mills shows a higher specific gravity and a lower porosity for the former.

General Electric Co.,
Schenectady, N. Y.

COMMUNICATED DISCUSSIONS.

C. F. Binns: Some years ago in England I had experience with the rolling table in the working of bone china. The pug mill as then designed was not suitable. It made the clay shorter instead of more plastic and bone china is a short body anyway. The only effective method before the rolling table made its appearance was hand-wedging, but the use of the table banished this entirely. It is quite true that for a large output the rolling table is slow but this is chiefly on account of the fact that the operation is not continuous. The table must be stopped, emptied and refilled for every charge. For bodies of the more plastic type no

doubt the pug mill is sufficient but the improvement of all wares lies in the direction of the use of less plastic clays and a higher percentage of ground material. Furthermore, these finer bodies are not likely to be used in such large quantities as are those of the commoner wares so that it does not seem unreasonable to expect that the rolling table will find profitable use for the finer products.

ALFRED UNIVERSITY,
ALFRED, N. Y.

B. E. SALISBURY: Something over ten years ago experiments were made in our plant with a kneading machine, which, I understand, was procured from abroad, and these seemed to indicate possibilities of attaining a more compact and plastic body. The experiments were not carried far enough, however, to definitely determine the possibilities of its use. The output, of course, as stated in the paper, is only a fraction of that of a pug mill, and therefore the labor cost of preparation of clay would be considerably higher.

We did not conclusively demonstrate that the better results from the kneading machine would offset the extra cost of the preparation of the clay by its use. I believe, however, that there are some possibilities along this line and am glad to have the matter come up for discussion.

ONONDAGA POTTERY CO.,
SYRACUSE, NEW YORK.

C. E. JACKSON: First, let me say that I am not in a position to discuss this question from a scientific angle for the reason that I do not have comparative data available. I have had four or five years of personal experience with an English or French kneading machine which was similar in design to the one discussed in the paper. We made a direct comparison between this machine and an American circular-barrel pug mill. The thing that militates against a complete installation of kneading machines in place of the pug mills is the fact that the kneading machines have only about one-sixth the capacity of the ordinary pug mill and very few factories are equipped to give sufficient space to machines of this character—especially to the number that would be required for ordinary production. In other words, the

relation between the comparative output of the pug mill and kneading machine is that the pug mill has about six times the output; as to the quality of clay delivered, there is no comparison. I believe that the clay after it has been on the kneading machine is better in all respects than clay that is hand wedged. The kneading machine also strengthens a weak body and produces a clay which works more smoothly.

Furthermore, for the manufacture of difficult pieces, the clay prepared by the kneading machine lends itself much more readily to their production than clay from the pug mill. For extremely delicate work, in which quality is the sole consideration, I believe the kneading machine to be the thing; for the average commercial work, where the requirements are not so exacting, I believe that the pug mill can be used to advantage for the reasons above noted.

WARWICK CHINA COMPANY,
WHEELING, W. VA.

THE DEVELOPMENT OF IMPROVED GOLD RUBY GLASS.

By H. T. Bellamy.

It has been a well-known phenomenon for sometime past that gold and copper produce a ruby color in glass which contains certain necessary constituents and which has been given a special heat treatment. The color is universally agreed to be due to the metals in suspension as colloids.

The ability of gold to exist in the colloidal state was first observed by Faraday while experimenting on the volatilization of gold. He found that gold in an atmosphere of hydrogen volatilized quite readily and that the vapor condensed as an intense ruby stain. Mostowitsch and Pletneff[1] have recently reported similar results. They melted gold in an unglazed porcelain boat, in streams of air, carbon dioxide, carbon monoxide, nitrogen and oxygen and held it at various temperatures up to 1400° C for a period of thirty minutes. No loss of gold could be detected. However, when heated in hydrogen the gold began to volatilize at 1250° C and the volatilization increased with temperature and time. The unglazed boat and the heating tube were colored an intense red—due to colloidal gold. It is probable that Au_2H_2—which is unstable, breaking up into Au_2 and H_2—was first formed. By heating copper in hydrogen a similar action was observed.

As an example of colloidal phenomena, gold ruby glass has been rather thoroughly investigated and the behavior of colloidal gold in this solid solution appears to be similar to its behavior in aqueous solutions, existing in both instances as colorless, green, red, blue, violet, or brown particles. When ruby glass is at the melting temperature the particles are colorless and when suddenly chilled they remain colorless, but if the glass is re-heated to the softening point, the particles become ruby. Further heating tends to produce other colors.

[1] *J. Russ. Metall. Soc.*, 1915.

Zsigmondy[1] says that at the melting temperature the gold is all in solution but at ordinary temperatures the colorless glass contains gold in two different forms—most of it being present in the supersaturated crystalloid solution and part existing as nuclei, which at higher temperatures serve as centers of growth.

Experimental.

The work which supplied the information for this paper was not undertaken to study ruby glass in general nor as a purely research proposition and on this account an exhaustive exposition of the problem is not to be expected. The manufacture of ruby glass was taken up to reproduce a ruby glass purchased in France, the importation of which had been discontinued since the war. A glass of the exact shade and possessing the requisite working properties could not be obtained from domestic suppliers. The treatment, to which the glass is subjected, is rather severe, as it must not shatter when introduced into a glass blower's flame, it must not discolor when heated to a very soft condition and it should be of such a nature that small lenses can be formed from the heated rod without subsequent annealing. The lenses so formed should be of uniform color, matching an accepted standard; should be free from surface cracks and other visible defects; and when mounted in a brass shell should withstand impacts of three pounds applied at the rate of 115 per minute.

A chemical analysis was made of the imported ruby glass and the molecular formula calculated as follows:

Analysis:

	Per cent.
SiO_2	38.35
PbO	54.48
K_2O	6.17
Sb_2O_3	0.67
R_2O	0.70
Gold	Present
B_2O_3	Not determined

Calculated Formula:

$$\left.\begin{matrix} 0.791\ PbO \\ 0.209\ K_2O \end{matrix}\right\} \quad 0.0173\ R_2O_3 \quad \left\{\begin{matrix} 2.05\ SiO \\ 0.0075\ Sb_2O_3 \end{matrix}\right.$$

[1] Zsigmondy, "Colloids and the Ultra-microscope."

While this work was being done the scarcity of potash was beginning to be evidenced and although the imported glass was made with a potassium compound, as was to be expected, it was decided to try to substitute a sodium compound.

The first melts were made in a small crucible-type gas furnace, using Battersea crucibles. After making a few trial batches to determine the proper quantity of gold to be added, a glass of the following formula was developed:

Ruby No. 1.

$$\left.\begin{matrix} 0.583\ PbO \\ 0.417\ Na_2O \end{matrix}\right\} \quad 0.0038\ B_2O_3 \quad \left\{\begin{matrix} 1.95\ SiO_2 \\ 0.0074\ Sb_2O_3 \end{matrix}\right.$$

The gold, which is not included in the formula, was prepared by dissolving ten karat sheet gold in aqua regia, separating the base melts in the ordinary manner, and diluting the gold chloride so that ten cubic centimeters contained one gram of metallic gold. The requisite volume of gold chloride was added to the sand of the batch and evaporated to dryness.

Ruby No. 1 appeared to match the imported ruby in color and preparations were made to melt a larger quantity. A No. 30 open glass-melting pot was used in the same type furnace and a batch eight times as large as the preceding one was prepared. The batch was added gradually and held at approximately 1300° C for fifteen hours when it was ready to work. Rods were made by the ordinary method of forming a bell-shaped gather. Each gathering of glass was allowed to solidify and, as the next coating was added, the previous coating developed the ruby color. After completion, the gather was re-heated in an improvised glory hole and drawn into rods.

It was very difficult to heat the gather sufficiently uniformly so that the rod would be of one color throughout its length. The smaller area next to the punty was usually overheated—showing light blue, purple and rose colors. Furthermore, the consecutive layers of the gather were frequently of different colors and when a lens was formed from the rod and viewed over a light it appeared streaked. The center of the rod showed the greatest tendency to discolor, as was to be expected—since the small initial gather

could readily become over-heated when dipped into the molten metal. However, when proper precaution was exercised in having the metal at a certain temperature, when the gathers were cooled to the proper degree, and when the re-heating was carefully controlled, a certain percentage of rod matching the standard shade was obtained from each gather.

Simultaneously with the development of ruby glass, experimental work was being carried on to produce other colored glasses to match imported glasses not obtainable since the war and also to develop opalescent colored glass of certain requirements which we were unable to procure from either domestic or foreign suppliers. The opalescence required was to be of such a degree that a lens should be of uniform color and opalescence when viewed normally over a light and the diffusion should be such that the quantity of light transmitted normally would compare favorably with that transmitted at 90 degrees from normal. To compare opalescent colored glasses on this basis, the sample lens was set in a tube in front of a small lamp mounted in a suitable revolving support in a photometer.

With the above requirements in mind, the development of an opalescent red was begun and after melting a few small batches to adjust the color and opalescence a glass having the following formula was tried out:

Opalescent Red No. 1.

0.502 PbO 0.342 Na_2O 0.156 CaO	0.0154 Al_2O_3	1.46 SiO_2 0.0134 Sb_2O_3

Lenses of Opalescent Red No. 1 had the proper color and degree of opalescence but the glass rods shattered while being heated in the glass blower's flame and the finished lenses shattered when subjected to the previously described impact test.

Although the quantity of cryolite used as an opacifier in opalescent red was considerably less than is present in our opalescent white glass, which withstood the impact test extremely well, the brittleness was attributed to its presence and it was decided to substitute tin oxide. After a few trial batches a glass having the following formula was developed:

Opalescent Red No. 2.

$$\left.\begin{matrix} 0.668\ PbO \\ 0.332\ Na_2O \end{matrix}\right\} \quad 0.0028\ B_2O_3 \quad \left\{\begin{matrix} 2.17\ SiO_2 \\ 0.0831\ SnO_2 \end{matrix}\right.$$

Opalescent Red No. 2 melted well, was readily worked into rods, and lenses formed from the softened rods fulfilled the requirements previously described. The resistance to impact was equal to that of the transparent ruby and the light diffusion was all that was desired. The opalescent red, being lighter in shade, is not as pleasing to the eye as the so-called ruby.

In developing Opalescent Red No. 2, a much smaller amount of gold was used than is present in Ruby No. 1, but as the concentration of tin oxide was increased to produce opalescence, a dark red glass resulted which in the form of a lens was almost opaque. The gold content was repeatedly reduced until Opalescent Red No. 2 of the desired properties were obtained. However, at an intermediate stage, when the gold content was about one-fifth of that used in the transparent Ruby No. 1, a glass was obtained which was quite similar in shade to Ruby No. 1. A perfect match for this glass and the former standard, the imported ruby, was produced by a slight adjustment arriving at the following molecular formula:

Ruby No. 2.

$$\left.\begin{matrix} 0.536\ PbO \\ 0.464\ Na_2O \end{matrix}\right\} \quad 0.029\ B_2O_3 \quad \left\{\begin{matrix} 1.96\ SiO_2 \\ 0.107\ SnO_2 \end{matrix}\right.$$

Lenses molded from Ruby No. 2 did not crack or shatter when subjected to the standard impact test and, unlike the lenses made from Ruby No. 1, were never streaked or off-color. The melting was carried on in No. 30 open glass-pots in a crucible-type gas furnace for a period averaging fifteen hours. The gather for rod drawing was shaped in the usual manner and each successive coating was allowed to cool before the next layer was added. The ruby color developed in the previous gatherings, as was the case when working Ruby No. 1, but always to a uniform color. The gather was re-heated to plasticity and drawn into rods in the usual manner. The rods and lenses made from Ruby No. 2 were always of a uniform ruby color. At first the precautions required in working Ruby No. 1 were followed but it was soon evident that

Ruby No. 2 would always develop the ruby color on re-heating and that the temperature of the glory-hole would not alter this color.

Ruby No. 3.

Quite recently we were called upon to produce a red glass enamel and finely powdered Ruby No. 2 was used with other suitable constituents. The enamel was not sufficiently red for the small thickness which was viewed over a light, and the amount of gold was trebled. The result was a very dark ruby referred to as Ruby No. 3 and which worked exactly like Ruby No. 2. The color developed upon heating to the softening point and it could not be changed except at a very high temperature when the ruby color disappeared, leaving a colorless glass.

The presence of a certain percentage of tin oxide, besides acting in the ordinary manner as an opacifier, apparently reacts to precipitate the gold in the red colloidal state. Its presence may affect the magnitude of the gold particles catalytically and produce this result or it may react to precipitate the gold particles as red hydrosols in the same manner that certain substances aid or retard the precipitation of colloidal gold in aqueous solutions.

Walker[1] states that gold particles may exist so finely divided in solutions that the ultramicroscope not only fails to reveal their presence as individuals, but fails even to detect any scattered luminosity in the solution when a powerful beam of light is concentrated in the solution and, since luminosity can be detected with gold particles of two millionth's of a millimeter in diameter, it is concluded that red colloidal gold particles have dimensions approximating the recognized magnitude of molecules, or approximately one millionth of a millimeter.

Ruby No. 2 and Ruby No. 3 and the opalescent red glasses which we have produced can exist in only two states—the red and the colorless. When at a high temperature, the absence of color is probably due to the fact that the gold is in solution. When colorless at ordinary temperatures, the gold particles, some of which it is assumed have separated out, are too small to be visible. Upon reheating, the gold particles grow until of visible size

[1] Walker's, "Physical Chemistry."

in which form they impart a ruby color to the glass. If the ruby colored glass is heated to the temperature at which the glass regains its solvent action, the red gold hydrosol again goes into solution. These glasses appear to be so constituted that the gold cannot assume the various colors which was noted in Ruby No. 1 and which it is generally believed is to be expected in gold ruby glass.

Conclusions.

It is rather difficult to draw general conclusions from this work regarding the composition of workable ruby glass for, as previously mentioned, this study was undertaken solely to produce glasses with predetermined properties. However, it may be stated that the range of stable red glasses is rather wide as the red opalescent described is quite light and Ruby No. 3 is very dark. The quantity of gold used to produce these shades of red varied from one part in ten thousand to one part in three thousand. The use of tin oxide to stabilize the gold and produce a ruby color with the minimum quantity of gold is new and novel and a patent has been granted. Two definite conclusions are apparent, namely: (1) a stable, reliable, gold ruby glass can be economically produced and (2) the presence of other colors is not a natural phenomenon of gold ruby glass, for when the necessary components are properly proportioned, the gold particles are either red or colorless.

CHEMICAL DIVISION—HAWTHORNE WORKS,
WESTERN ELECTRIC COMPANY, INC.,
CHICAGO, ILL.

COMMUNICATED DISCUSSIONS.

F. CARDER: The paper is very interesting and shows that the author has given the subject careful thought.

The very small lenses which were shown by Mr. Bellamy should not have been difficult to make or match, either for color or for the physical standards set, especially when so high a content of PbO could be used in the batch.

Has Mr. Bellamy tried his Ruby No. 1 after gathering a mass from the pot, and cooling until it was below a red heat and then raising the temperature slowly by heating in a glory-hole? Has

he subjected his various trials to blowing out with the blowpipe or flashing his ruby on a flint base? While the rods or lenses may be good enough in color for the purpose intended, I am inclined to think that upon treating his ruby as suggested, he would find discolorations such as he mentions, *viz.*, blue, purple or brownish streaks which usually occur when gold ruby is subjected to a too sudden transition from the colorless state (or state of solution) to the colloidal or crystalline state.

The proportion of gold to the batch, 1 to 3000, or even 10,000, is, to my mind, excessive. Josiah Wedgewood found that one part gold to 20,000 batch colored glass red.

I was somewhat surprised to note that Mr. Bellamy considers the introduction or use of SnO_2 in gold ruby as an innovation. When gold ruby was discovered it was made with "purple of cassius," which some chemists believe to be a gold stannate. I believe that Kunkel made his first gold ruby with "purple of cassius," samples of which are still to be seen in the art museums in Dresden. Berzelius states that "purple of cassius" contains 28.2 per cent of gold to 64 per cent of tin oxide. To my knowledge tin oxide has been used for a great many years and in my experience in manufacturing glass I have never known any formula worthy the name of gold ruby which did not contain tin oxide. Many other oxides are used to give reds varying from a yellowish red to a purple, such as U_2O_3, Fe_2O_3, and CoO.

STEUBEN GLASS WORKS,
CORNING, N. Y.

E. C. SULLIVAN: Mr. Bellamy's method of intensifying the red color of gold ruby by means of tin oxide recalls the similar use of tin oxide with copper in making qualitative tests by means of the blowpipe applied to the bead of molten borax glass. In testing for copper, tin oxide is added to the bead to assist in the formation of the color of reduced copper, and a test for tin depends upon subjecting the borax bead containing copper to such a reducing condition that the ruby color of the copper will develop if tin is present, not if it is absent.

CORNING GLASS WORKS,
CORNING, N. Y.

R. L. FRINK: It occurs to me that the author's statement in the last paragraph, last three lines: "The presence of other colors is not a natural phenomenon of gold ruby glass, for when the necessary components are properly proportioned, the gold particles are either red or colorless," is not compatible with the results as found by Zsigmondy and others; that gold, when existing in colloidal solution, or in aqueous solution, irrespective of the components, may produce colors ranging from red to blue.

I also cannot understand how it is possible to obtain patents upon the use of tin, or its salts, to either stabilize or in any manner affect the characteristics of gold in glass, for I had supposed that this was an old, in fact very old, method of producing ruby glass, at least I have heard of it for the past 25 years.

THE FRINK LABORATORIES,
LANCASTER, OHIO.

H. T. BELLAMY: 1. Practically all gold ruby glass described in the literature contains potash as an alkali. In view of the scarcity of potash at the time, soda was substituted, and the resulting glass was equally as satisfactory as ruby glass made with potash.

2. A ruby glass designated as "Ruby No. 1," which matched the imported ruby glass, and like it and other ruby glasses described in the literature, was changed to blue, purple or brown under certain conditions, was developed.

3. An improved "Ruby No. 2" was developed which does not discolor. This result is ascribed to the high percentage of tin oxide. Of course, those familiar with the art, know that "purple of cassius" has been extensively used in making ruby glass and that it contains a certain amount of tin oxide but experience has shown that the ruby glass so made is not stable. The author claims that when sufficient tin oxide is present in a properly proportioned batch, the ruby glass will not discolor, and that this feature is an innovation.

4. Another advantage in using a high percentage of tin oxide is the production of ruby glass with a minimum quantity of gold. While there is no doubt that red glass has been made with one part gold in twenty thousand parts batch, the literature gives

ruby glass formulas ranging from one part gold in one thousand parts batch to one part gold in fifteen hundred parts batch. The usual quantity was being used and the introduction of tin oxide reduced the gold content to one-fifth of its original amount.

It should be borne in mind that this paper is the story of a manufacturing investigation and that the statements made were based on information obtained from a large number of glass batches. The title "Gold Ruby Glass" under which the paper was presented, is no doubt rather broad and it has been revised to "The Development of Improved Gold Ruby Glass." It might appear that the glass described should be restricted to the manufacture of glass rod and small lenses. However, Ruby No. 2 has been successfully made into tubing as well as blown, flashed and pressed parts, and in conclusion the author desires to emphasize that this glass has been subjected to all conceivable temperature transitions and never has a particle of glass been observed which was other than ruby or colorless.

AMERICAN CERAMIC SOCIETY.

Acquisition of New Members during April, 1919.

Resident Associate.

Allison, LeRoy W., "Brick and Clay Record," 170 Roseville Ave., Newark, N. J.

Bausch, Frederick E., 1105 Chemical Bldg., St. Louis, Mo.

Dolman, C. D., Northwest Magnesite Co., Chewelah, Wash.

Geller, Roman F., Bureau of Standards, Pittsburgh, Pa.

Graham, E. H., Washington Iron Works, Los Angeles, Cal.

Gregori, L. P., Midland Terra Cotta Co., Chicago, Ill.

Harding, Browne, Providence Base Works, Providence, R. I.

Huston, C. H., Chattanooga Stamping & Enameling Co., Chattanooga, Tenn.

James, W. Roy, 118 W. 14th St., Marion, Ind.

Jensen, James L., Empire China Works, Brooklyn, N. Y.

Owens, Frank W., Canton Stamping & Enameling Co., Canton, Ohio.

Rand, C. C., National Lamp Works, Cleveland, Ohio.

Risch, Edward J., Midland Terra Cotta Co., Chicago Ill.

Sharp, Chester L., The Frink Laboratories, Lancaster, Ohio

Silvers, James L., Trent Tile Co., Inc., Trenton, N. J.

Taylor, R. F., Pilkington Bros., Ltd., Niagara Falls, N. Y.

Corporation.

Beaver Falls Art Tile Co., Beaver Falls, Pa.

Laclede-Christy Clay Products Co., St. Louis, Mo.

Midland Terra Cotta Co., 115 Lumber Exchange Bldg, Chicago, Ill.

NECROLOGY.

Owen Carter, of Poole, England, was educated in private schools and on leaving entered the encaustic tile business of Carter and Company, which had been established by his father about five years before. The first few years of his business career were spent at the London office of the firm, but he subsequently went to Poole and undertook the works management which he retained to the time of his death, in February, 1919.

Mr. Carter was deeply interested in scientific subjects, particularly those bearing upon the practical side of the business, and his keen appreciation of art did much to influence the artistic production of the firm. The business, which was established in quite a small way in 1873, grew to be one of the most important in England, comprising three large factories doing a considerable home and export trade in floor and wall tile, constructional faience and terra cotta, mosaic, fire-places, fancy pottery, etc. The development of these various branches were largely due to Mr. Carter's initiative and practical skill. Of a very retiring disposition, Mr. Carter never took active part in public life but devoted his energies to business and to "doing his bit" in a quiet, unostentatious way.

Mr. Carter was a member of the Society of Friends and was faithful to the traditions of that body in the simplicity and honesty of his life. He was elected to Active Membership in the American Ceramic Society at the last annual meeting, but he did not live to learn of this. He died in his fifty-seventh year, after an illness extending over four months.

Hugo J. Lundgren was born in Sweden, in 1881, and was educated partly in his native country and partly in Germany. He entered the employ of the Canadian General Electric Company, at Petersborough, Ontario, in 1913 and was continuously engaged with this concern until his death.

He specialized in electrical porcelain and succeeded in bringing his department to a high degree of excellence. He was attacked

by the influenza epidemic during a professional visit to various porcelain factories and reached his home in an advanced stage of sickness. He died February 24, 1919, at the age of thirty-eight.

Mr. Lundgren was elected to Active Membership in the American Ceramic Society at the Pittsburgh meeting but did not live to receive the notice of this. He was a member of the American Institute of Electrical Engineers, before the Toronto branch of which he read last winter a valuable paper on porcelains for electrical purposes.

William A. Kemp, of Toronto, Canada, died suddenly on March 18, 1919, at Pine Forrest Inn, Summerville, South Carolina. His health had never been robust since an attack of typhoid fever, contracted when he was traveling in Italy some years ago, and he had gone south to try to regain it.

Mr. Kemp was born in Clarenceville, Quebec, fifty-six years ago and went to Toronto in 1886 to engage in business with his brother under the name of the Kemp Manufacturing Company, which afterwards developed into the Sheet Metal Products Company of Canada, Limited. Mr. Kemp was the vice-president of that Company and was also president of the MacDonald Manufacturing Co. of Toronto, Limited. Through his experiments and interest the enamel ware industry was founded in Canada, replacing the German and Austrian products which then supplied the market.

Mr. Kemp was a man of sagacity, sympathy, and friendliness and was generous in the use of his means. He was particularly interested in all sorts of work for young men and boys, and in the missionary enterprises of the Methodist denomination of which he was a member. His family consists of his widow, three daughters and one son, Captain Clarence Kemp, who is still in France with the Canadian Expeditionary Forces.

A. Lawrence Jensen, of Brooklyn, New York, died at the Hotel Hollywood, Southern Pines, N. C., on February 14, 1919. Mr. Jensen was one of the directors of the Empire China Works, Brooklyn, and had been connected with the porcelain industry since 1890.

Mr. Jensen is survived by his wife, two daughters, a sister, and a brother, Chas. H. Jensen, an Active Member of the Society.

ACTIVITIES OF THE SOCIETY.

The following motions have recently been passed by the Board of Trustees:

April 8th. It was voted that all discussions and votes by members of the Board of Trustees be directed to the President, as chairman of the Board, and that copies be sent to all other members of the Board when such are mailed to the Secretary by each member. It was voted that in case the President does not wish to second a motion he immediately notify the maker who shall secure a seconder.

The appointment of Professor A. V. Bleininger as representative of the American Ceramic Society on the Division of Chemistry and Chemical Technology of the National Research Council was confirmed by the Board.

April 10th. It was voted to hold the Summer meeting, 1919, in Buffalo, Niagara Falls, and Cleveland, the meeting to convene at the Hotel Statler, Buffalo, on Monday evening, August 4th.

April 14th. It was voted to give a complimentary subscription to the JOURNAL of the Society to the Library of the Chemists' Club, New York City.

April 18th. It was voted to hold the Twenty-second Annual Meeting of the Society at Philadelphia, February 23–26, 1920, with headquarters at the Hotel Walton.

April 24th. On the recommendation of the Committee on Papers and Programs, it was voted that the papers that may have been published in the JOURNAL previously to the Annual Meeting shall appear on the printed program, and their authors shall be given the privilege of presenting them on the floor at the meeting; that the program shall announce the names of those who have signified a desire to discuss a paper; and that the Committee shall demand that copies, or at least abstracts, of all papers be in the hands of the Committee by February 1st, unless previously printed.

April 24th. It was voted to nominate Dr. Robert B. Sosman and Mr. H. F. Staley as representatives of the Society upon the Committee on Ceramic Research, National Research Council (see editorial in March number).

Action of the Society.

April 18th. It was voted, by letter ballot, to adopt the Amendments to the Rules, proposed by the Committee on Rules at the Annual Meeting, Pittsburgh, 1919.

ACTIONS TAKEN BY THE BOARD OF TRUSTEES DURING THE YEAR 1918–1919.

At a meeting of the Board of Trustees at Pittsburgh, it was voted to publish monthly the resolutions and motions passed by the Board, so that the members of the Society may be apprised of the actions taken from time to time.

The following is a summary of the motions passed during the year 1918–1919:

Professor G. H. Brown was elected Editor and Miss M. M. Gill as his assistant. Miss Norah W. Binns was appointed assistant to Professor Chas. F. Binns, the Secretary. Early in the year the Editor was empowered to submit a monthly bill for office expense, and later the President was empowered to submit a bill for stenographic assistance. The sum of $100 was appropriated for the expenses of the booth of the Society at the Chemical Exposition. Twice during the year it was found possible to invest some of the Society's funds. It was voted to invest $3,000 in the Fourth Liberty Loan and $2,000 in U. S. Treasury Certificates.

The Committees on Coöperation and Local and Student Sections were appointed by the President and approved by the Board. Mr. A. F. Greaves-Walker was appointed chairman of the War Service Committee and Mr. R. C. Purdy, chairman of the Membership Committee.

The Secretary was empowered to accept applications for Associate and Contributing Membership for one year. The seventeen Associates nominated to Active Membership at the Annual Meeting (1918) were voted upon and elevated.

When the JOURNAL was launched it was found that the postal regulations necessitated a change in the wording of the Rules, with regard to the subscription price to members. This change was approved by the Board of Trustees and a resolution was passed by the Society at the Summer Meeting.

The Board voted to place fifty copies of each issue of the JOURNAL at the disposal of the Membership Committee for the purpose of soliciting new members.

A discount of 20 per cent to dealers upon the subscription price of the JOURNAL was decided upon.

At the Summer Meeting the Society voted to support Mr. A. F. Greaves-Walker, chairman of the Industrial Furnace Section of the U. S. Fuel Administration, by assisting in the securing of volunteer inspectors. The Board voted to give space in the JOURNAL to advertise for these.

The methods of formation of Professional Divisions was decided upon as follows:

I. "A petition may be presented by not less than ten members in good standing, of whom three or more shall be Active, who are interested especially in some phase of ceramic work sufficiently broad to warrant the formation of a special Division. This petition shall go to the President, who shall then appoint a representative committee to consider the advisability of forming such a Division, and to proceed with the organization if the decision is favorable."

II. "When the initiative is taken by the Board of Trustees in order to stimulate the growth of the Society, the President shall appoint a representative man to furnish the initiative. He shall select his own committee." It was later voted that Divisions on Glass, Enamel, Pottery and Porcelain, Refractories, Brick and Tile, Terra Cotta and Faience, and Abrasives, should be established.

Pittsburgh, Pa., was chosen as the place of the Twenty-first Annual Meeting.

The Board voted to advertise the "Directory of Dealers" in two successive issues of the JOURNAL.

The stock of certain volumes of the Transactions having become low, it was voted to purchase a sufficient number of these to complete fifty sets, which should then be held for sale in sets only.

It was voted that 200 copies of each number of the JOURNAL be reserved at the time of issue for sale in complete sets only, and that an additional 200 be likewise reserved for sale in complete volumes only. It was the sense of this resolution that a "complete set" should consist of the first five volumes of the JOURNAL and such additional volumes as may have been issued up to the date of the sale, and that a "sale" should be the actual selling of volumes and not the furnishing of them in consideration of payment of membership dues. It was voted at the same time that copies of the volumes of Transactions and of the JOURNAL be furnished to members who have allowed their dues to lapse, only after the number reserved for sale has been provided. Furthermore, that in cases in which the volume for a certain year's dues is not available, the member shall have the option of selecting any available volume or having the dues apply to the succeeding year.

The board voted that, beginning with Volume 2, Number 1, authors of papers published in the JOURNAL shall be furnished with reprints, free of charge, in any number, not to exceed 100, which shall be requested.

CHAS. F. BINNS, Secretary.

LOCAL SECTIONS.

Chicago Section.

The Sixth Meeting of the Chicago Section of the American Ceramic Society was held in connection with the Forty-first Annual Convention of the Illinois Clay Manufacturer's Association, at the La Salle Hotel, Chicago, April 9, 1919. After an appropriate talk by Mr. W. D. Gates, acting as Chairman *pro tem*, the following papers were presented:

"Discussion of the Humidity System of Drying Clay Wares," by Mr. B. S. Radcliffe, Midland Terra Cotta Co., Chicago.

"Heat Insulation for Industrial Furnaces," by Mr. H. N. Haberstroh, Celite Products Co., Chicago.

"Notes on Zirconium," by Mr. E. E. Libman, University of Illinois, Urbana, Illinois.

Mr. F. B. Ortman joined in the discussion of humidity drying and contributed ably to this interesting subject. All papers were enthusiastically received and discussed.

Professor C. W. Parmelee enlightened the Society on the present status of the Ceramic Department at the University of Illinois, and informed the members that the Board of Trustees had authorized the Chicago Section to nominate four members as its representatives on the Advisory Committee of the Ceramic Department. The following men were unanimously appointed by the Section:

Mr. E. F. Achardt, General Manager, Federal Plate Glass Co., Ottawa, Ill.

Mr. Chas. S. Reed, President, Chicago Retort and Fire Brick Co., Ottawa, Ill.

Mr. Theo. G. Dickinson, President, Marquette Cement Co., Chicago, Ill.

Mr. F. H. Fall, Jr., Benjamin Electric Co., Chicago, Ill.

It was voted that the Chair appoint one member to coöperate with representatives of the Societies listed below, in fostering the close and lasting affiliations of these Societies.

Illinois Clay Manufacturer's Association.
Illinois Paving Brick Manufacturer's Association.
Illinois, Indiana Division, American Face Brick Association
Indiana Brick Manufacturer's Association.
Illinois Drain Tile Manufacturer's Association.
American Ceramic Society.

Adjourned.

H. T. BELLAMY,
Secretary-Treasurer.

New York State Section.

The New York State Section of the American Ceramic Society held a meeting in Syracuse, N. Y., Friday and Saturday, May 9th and 10th, at which the following program was presented:

Friday, 10 A.M., Business meeting of the Section.

At the Friday afternoon session the following interesting papers were presented:

"Address of Welcome," by B. E. Salisbury, Onondaga Pottery Co.

"Mechanical Phases of Ceramic Engineering: Drying and Firing," by L. E. Barringer, General Electric Co.

"The Manufacture of Abrasive Wheels," by S. C. Linbarger, Carborundum Company.

"The Porcelain Situation in the United States," by Prof. C. F. Binns, Alfred University.

"Fuel Regulation in Ceramic Plants," by Prof. G. A. Bole, Alfred University.

"Some Observations on the Shrinkage of China Bodies," by Mark A. Haley, Onondaga Pottery Co.

"How to Make Enamels Durable," by Prof. J. B. Shaw, Alfred University.

On Saturday parties visited the Onondaga Pottery and the Paragon Plaster Company.

The meeting was very well attended, there being members present from every section of the State. In addition to the members of the New York State Section the session was attended by brick manufacturers of western New York.

At the business meeting much business was transacted, and among other things it was decided to call a meeting of the New York State Section at Buffalo, at the time of the August meeting of the Society. The officers elected for the current year were as follows:

Chairman—S. C. Linabarger.
Secretary-Treasurer—J. B. Shaw.
Councilor—L. E. Barringer.

Adjourned.

J. B. SHAW.
Secretary-Treasurer.

Northern Ohio Section.

The fifth meeting of the Northern Ohio Section of the American Ceramic Society was held at the Portage Hotel, Akron, Ohio, on April 28th.

In the morning a visit was made to the plant of the Goodyear Tire and Rubber Co. After lunch at the hotel a trip was made through Plant No. 1 of the Robinson Clay Products Co. This plant is devoted to the manufacture of stoneware, including large and intricate chemical shapes.

A short business meeting preceded the program. The first paper of the afternoon was given by Prof. Hewitt Wilson, Ohio State University, on "Glaze Studies." This was followed by a talk on "The Present Trend in Porcelain Manufacture," by Mr. E. T. Montgomery of the Jeffery-Dewitt Co., Detroit, Mich.

Mr. William P. Blair, Secretary of the National Paving Brick Manufacturers' Association, gave a very interesting talk dealing with present day requirements for both art and utility in all kinds of brick construction.

The program closed with an illustrated talk by Mr. E. P. Poste, Elyria Enameled Products Co., Elyria, Ohio, on "The Manufacture of Enameled Ware."

The attendance was good in spite of the bad weather.

Adjourned.

B. A. RICE,
Secretary-Treasurer.

Pittsburgh District Section.

A meeting of the Pittsburgh District Section of the American Ceramic Society was held at the Potter's Club, East Liverpool, Ohio, on Wednesday evening, April 23, 1919.

Mr. W. E. Wells, of the Homer Laughlin China Co., presented an interesting discussion of "Cost Accounting in Pottery Manufacture."

Mr. F. W. Walker, Sr., of the Beaver Falls Art Tile Co., Beaver Falls, explained some of the work which has been done recently in Washington in establishing prices for various clay products.

The meeting was very well attended and thoroughly enjoyed by all.

F. H. RIDDLE,
Secretary-Treasurer.

Adjourned.

Eastern Section.

The New Jersey Clay Workers Association and Eastern Section of the American Ceramic Society will hold a meeting at the Trenton Country Club, Trenton, N. J., on Tuesday, June 24th. The usual excellent program is being arranged for the morning and afternoon sessions of this meeting. Members of the Society are cordially invited to attend, particularly those residing in New Jersey, New York City, Eastern Pennsylvania, Eastern Maryland and Delaware.

Applications for membership in the Eastern Section should be forwarded to G. H. Brown, Box 444, New Brunswick, N. J

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The Value of Fuel Saved in One Year

¶ Actual records were kept for 365 days of the burning of 9-inch, high-grade, refractory brick in one continuous tunnel kiln and in seven 30-foot round kilns, during which time 5,110,000 brick were burned in the tunnel kiln as against 5,040,000 in the seven round kilns.

¶ But this isn't all—the actual labor saving amounted to $5,808.00. Taking into consideration the necessary items of depreciation, interest on plant, maintenance and repairs, the average yearly cost for burning 1,000 brick in the continuous tunnel kiln system was $2.95 as against $6.20 in the round kilns.

¶ If you are really interested in the greater efficiency of burning, you will let us tell you more about the actual accomplishments of

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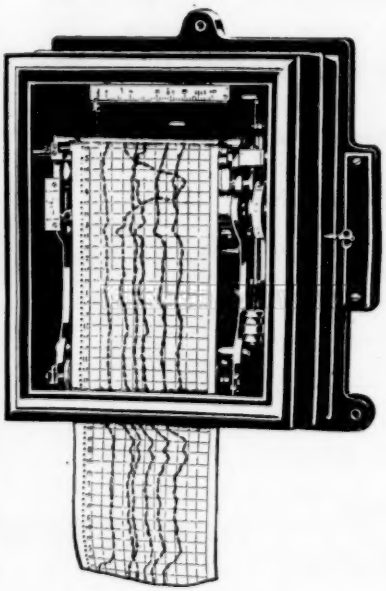

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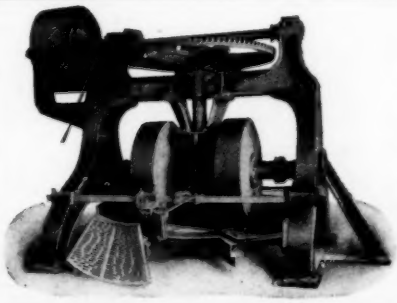

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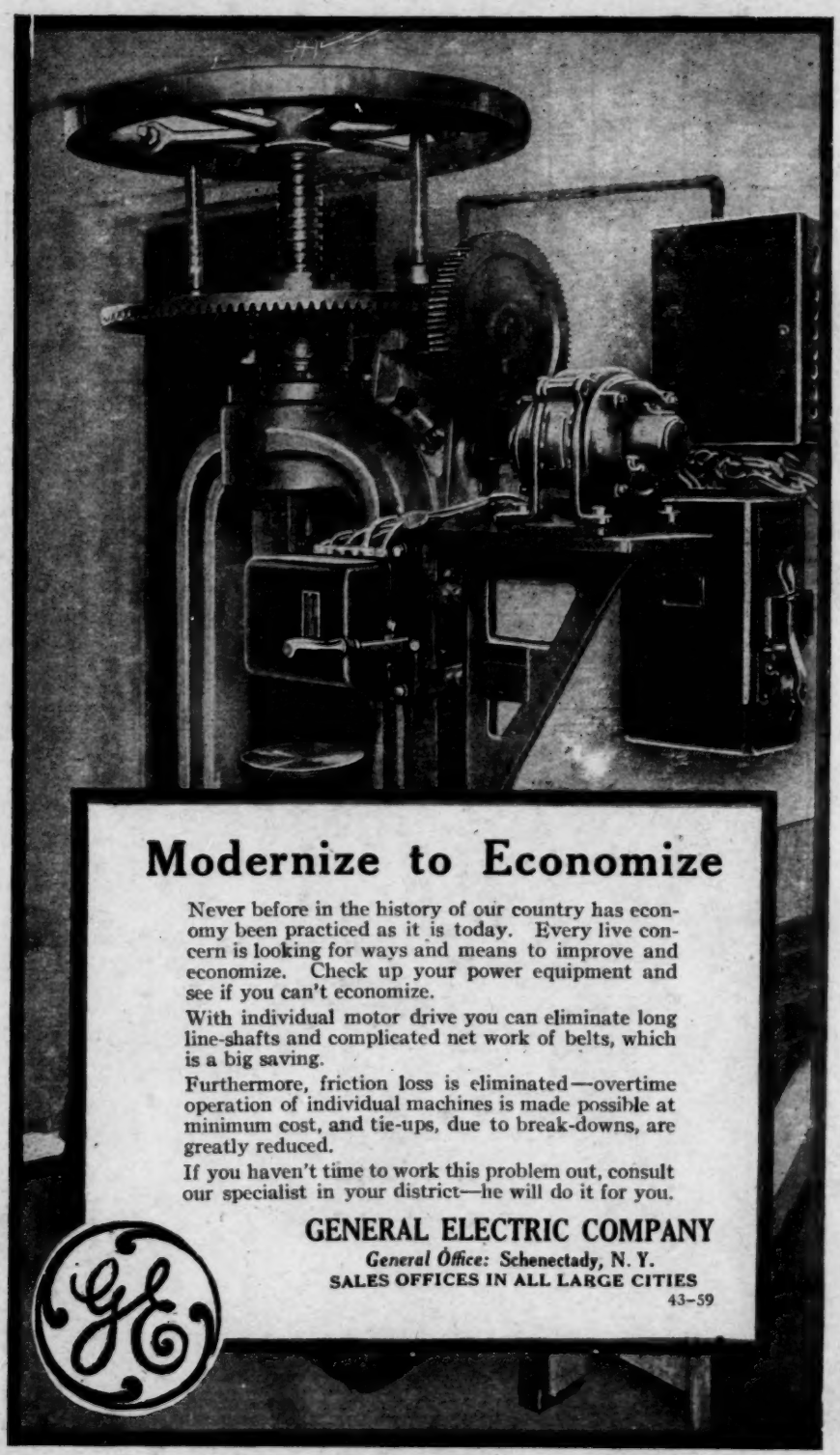

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